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Procedures Manual For The Recommended ARB Size Specific Stationary Source Particulate Method (Emission Gas Recycle)

Attachment No. 3 to the Final Report for
ARB contract A3-092-32
"Recommended Methodology for the Determination of Particle Size Distribution in Ducted Sources"
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Foreword

Broadly speaking, one can divide the ARB current or potential needs with respect to particle sizing into three classes: (1) regulatory, including setting of emission standards and compliance testing; (2) control strategy development (emission inventories) and permitting (control device selection, etc.); and (3) basic research and development. Of course, considerable overlap exists in the types of information needed for each of these activities.

As currently foreseen, possible regulatory action on emission may take place based on one or both of two particle size classes. The first, and more likely, of these possible regulatory actions is related to the PM_{10} class (particles having aerodynamic diameters smaller than 10μm) for which a state ambient air regulatory standard has already been set. The second class for possible action concerns fine particles, those particles having aerodynamic diameters smaller than 2.5μm. In either case, the regulations may be chemical species and/or industry or process specific as well as particle size specific. If particle size specific regulations are set, compliance test methods would be a concomitant necessity. Development of an emissions inventory would be a preliminary activity prior to such regulatory action - such an inventory is currently being constructed within the ARB for the PM_{10} class based on such information as is now available. The number of size classes (and the resolution) required for these activities is obviously limited - only one or two size cuts are needed and relatively simple and inexpensive techniques are desirable if they are to be used as compliance tools.

Greater resolution than that needed for compliance testing is desirable for activities related to permitting. The performance of many (or most) particulate control devices can be predicted for a given source from a broad base of experimental data and models provided that the gas stream conditions and the particle size distribution of the material to be collected are known. In most cases, the critical size range for estimating the probability of achieving a required level of control in this fashion is from about 0.1μm to 20μm. Resolution into about eight size classes, evenly spaced in terms of the logarithm of particle diameter, over the latter range is generally sufficient. In some instances specific target chemical species are of interest which may not be homogeneously distributed with respect to particle size. In those cases, size segregated samples suitable for chemical analysis may be needed in addition to data for overall size distribution. Three to five size fractions may be adequate for this application.

The needs of the agency with respect to basic research presently fall into three areas. The first is providing support for the activities previously described; the second is the development of a data base characterizing the principal types of industrial emission in the state; and the third is concerned with particulate chemistry. At present the main concerns in the area of particulate chemistry are primarily emissions of toxic substances and substances which act as catalysts in secondary aerosol formation.

This document describes detailed procedures for measuring PM_{10} particulate emission rates of stationary sources. The method described herein may be considered as a possible PM_{10} measurement method for compliance testing. Furthermore, it may be used for total particulate matter emissions measurement and in some situations, to provide size segregated samples for chemical analysis.

Abstract

This report concerns the use of the Emission Gas Recycle (EGR) Sampling System for PM_{10} measurement of particulate missions at stationary industrial sources, and is an attachment to the Project Final Report. The report briefly presents the concept of EGR and describes the proto-type system constructed by Southern Research Institute under contract to the U.S. Environmental Protection Agency. It also provides a detailed field protocol for use of the EGR system at stationary industrial sources, describes data reduction, and quality assurance and control. The report includes a history of the PM_{10} classifier calibrations and a history of the field trials of the EGR systems. Appendices containing microcomputer program documentation (for setup and reduction of field data), as well as system drawings have also been included.

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INTRODUCTION

Procedures for measurement of size-specific particulate emissions (such as PM_{10}) are more complex, but similar to, those for total particulate sampling by EPA Reference Methods 5 or 17. Potential sampling biases exist due to variations in the spatial distribution of particulate concentrations across the sampling plane defined by the duct cross-section. Likewise, temporal variations in particulate concentrations due to process variations can cause inaccurate or unrepresentative results. Also, if the gas velocity entering the sampling nozzle is not the same as the local duct velocity, particulate matter will be selectively depleted or enriched in the sample gas stream due to inertial separation at the nozzle entrance. EPA Reference Methods 5 and 17 deal with these problems by specifications on the sampling location to minimize stratification and by sampling isokinetically at an array of points spanning the sample plane. Isokinetic sampling is accomplished by measurement of duct velocity at each point and adjustment of the sample train flowrate so that it is proportional to velocity.

Size-specific emission measurements are accomplished by sampling through an inertial size-separation device. The procedure and equipment must deal with the same problems described above while, in addition, maintaining a constant flowrate through the separator to provide the desired size cut (10μm for the present purpose). This constraint on flowrate causes there to be substantial differences between sampling methods for PM_{10} and those for total particulate matter. The constraints of isokinetic sampling and a specified flowrate for the size cut directly conflict, resulting in a requirement for additional hardware.

The method described here is under development by the US EPA as a PM_{10} source sampling method. It uses a special sampling nozzle which allows isokinetic sampling while maintaining the specified flowrate for a 10μm size cut provided by an instack particle classifier. The sampling train incorporates the principle of emission gas recycle (EGR). It allows a variable fraction of conditioned and filtered exhaust gas from the sampler to be added to the sample stream between the sample nozzle and the inertial classifier. This allows a preselected constant flowrate to be maintained through the inertial classifier while the gas flowrate into the sampling nozzle is adjusted to remain isokinetic with the local duct velocity. Although the method might, in principle, be applied with any type of inertial classifier, it has been tested only with a single stage cyclone for PM_{10} measurement to date. Therefore its use in other applications is not currently recommended.

The emission gas recycle concept was originally developed into a prototype sampling train at the U.S. Environmental Protection Agency facilities at Research Triangle Park by making modifications to a commercially available Method 5 sampling system[1]. This system was subsequently evaluated, in laboratory and field situations, at Southern Research Institute (SoRI) under EPA contract.[2,3,4] In continuation of this work, during the summer of 1985,

two "second generation" versions of the EGR system were constructed at SoRI. It is this second generation system which is specifically described within this manual.

The principle of operation of the EGR train is illustrated in Figure 1. Stack gas is extracted isokinetically at volumetric flowrate Q_s. If the stack moisture fraction is B_{ws}, the sample flow consists of $Q_s \cdot B_{ws}$ moisture and $Q_s(1-B_{ws})$ dry gas flow. At the mixing point a flow, Q_r, of dry recycle gas is added to the sample stream to bring the total flowrate to the predetermined constant level, Q_t. In the impingers or condenser, the moisture content $B_{ws} \cdot Q_s$ is removed. After the pump and total flow metering element, the recycle flow Q_r is diverted by means of adjustable valves. By mass balance, in a leak-free system, the remaining flow which passes through the dry gas meter and orifice will simply be $Q_s(1-B_{ws})$, exactly as would occur in an isokinetic sampling train without gas recycle.

Other potential problems which were considered in design and selection of hardware for the EGR train, were deposition of particles smaller than 10μm upstream of the sizing device, bounce and reentrainment of particles larger than 10μm and inaccuracy in the cutoff diameter due to error in setting the total flowrate. A block diagram of the prototype train is shown in Figure 2. The gas sample which contains particulate matter enters through the sample inlet of the mixing nozzle. Oversize particles are removed by the classifier, after which the desired particulate sample is collected on the sample filter. The gas then passes through an impinger train or ice-cooled condenser, followed by a sealed pump controlled by valves V_1 and V_2 for coarse and fine flow adjustment, respectively. From this point in a standard isokinetic sampling train the gas would pass directly to the dry gas meter and sample orifice and finally be exhausted. In the train as modified for EGR, after the gas exits the pump (sealed, oiless) it passes through an absolute (HEPA) filter and the first of two laminar flow elements where the total flow is measured. The gas stream is then split into the recycle and sample lines. The recycle gas flow is controlled by valves V_3 and V_4, and measured by a second laminar flow element. The sample flow is monitored in the usual manner, using a dry gas meter and a calibrated orifice. Valve V_5, at the inlet to the dry gas meter, was added to the system to extend the range of control to higher recycle percentages by adding back pressure to the sample flow line.

Figures 3 through 7 show the control module for the US EPA second generation EGR system. As can be seen, the appearance of the module is similar to that of a standard Method 5 sampling box, with the exception of the total, inlet, and recycle magnehelics, the recycle and sample (back pressure) control valves, and the recycle gas outlet. The PM_{10} size-fractioning cyclone used in conjunction with the EGR system is shown in Figures 8 and 9. The cyclone chosen as the PM_{10} sizing device was the commercially available version of SoRI/EPA's Cyclone I (of the 5-Stage Series Cyclone). The particular cyclone used was of the Flow Sensor type, currently marketed by Andersen Samplers, Inc. It should be noted, that for the interest of clarity the side view of the EGR PM_{10} Cyclone Sampling Device (Figure 9) is shown with the recirculating nozzle pointing 180° from the nominal position. As shown, the device would not fit through a typical four-inch sampling port.

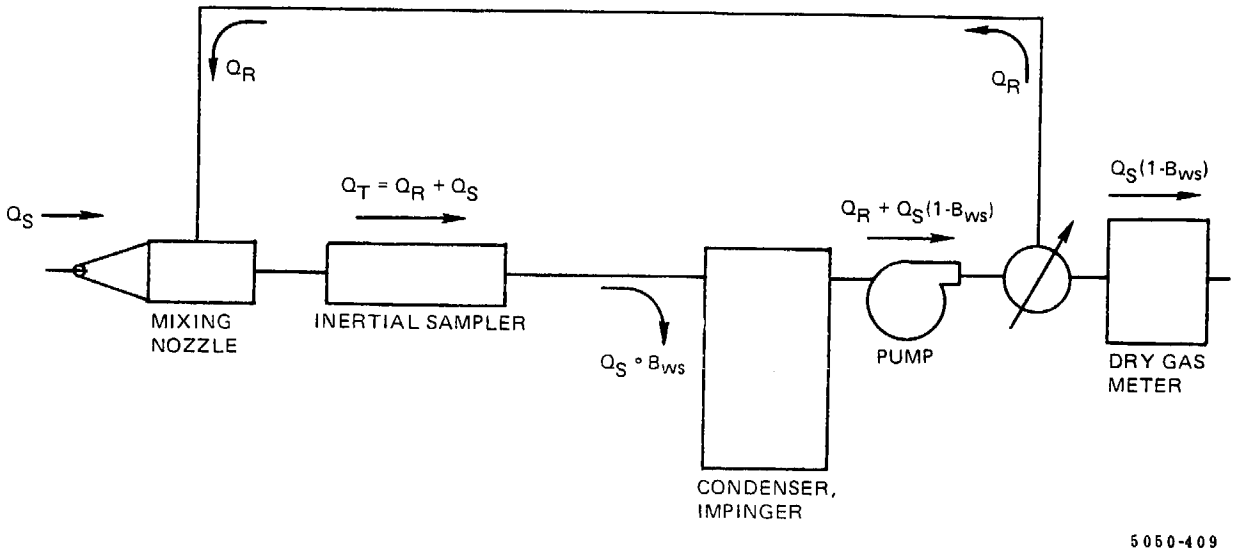

Figure 1. Gas flow in emission gas recycle (EGR) train (Harris, et al., 1981).

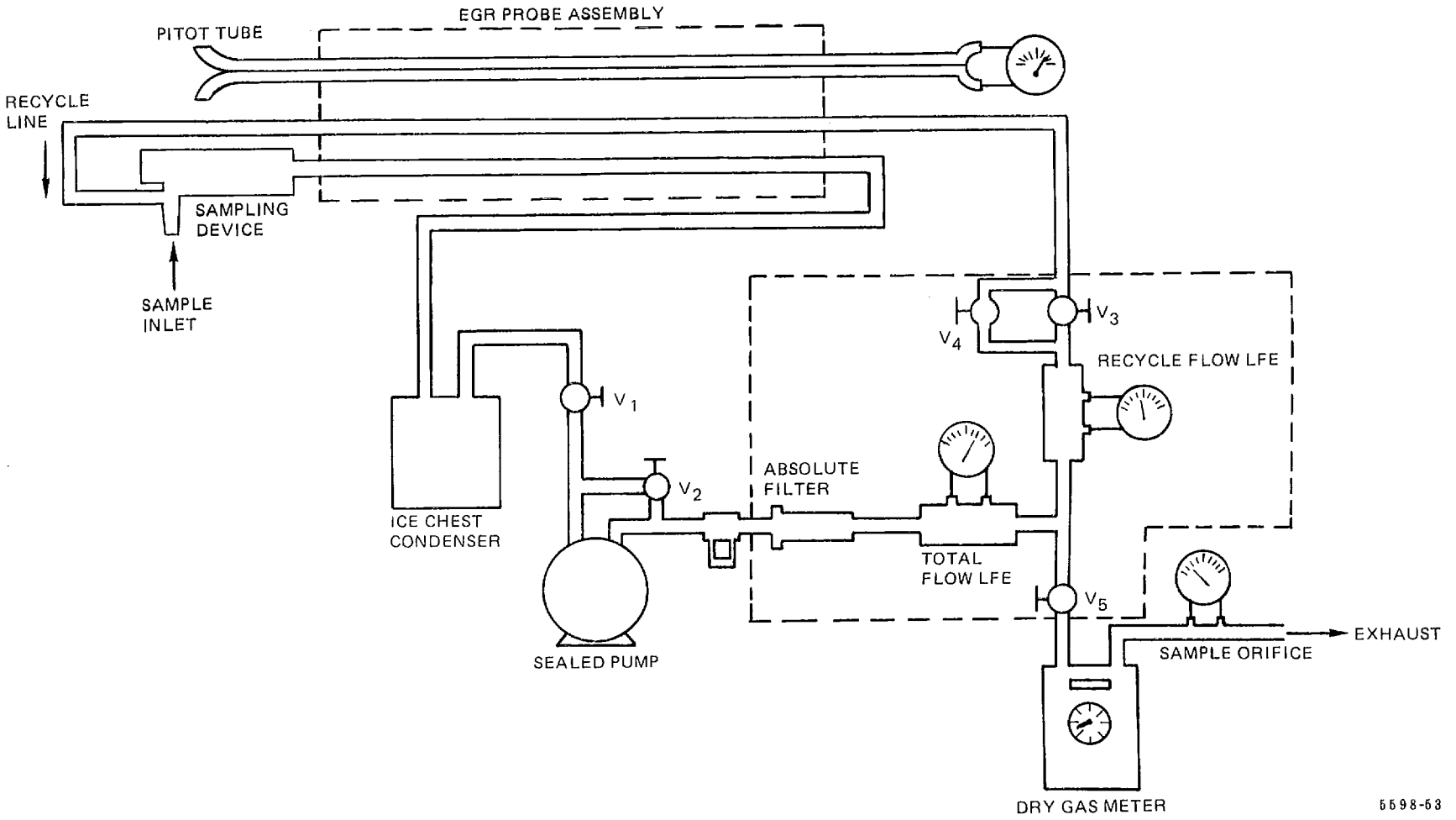

Figure 2. Schematic of the exhaust gas recirculation train (Williamson, et al., 1984).[2]

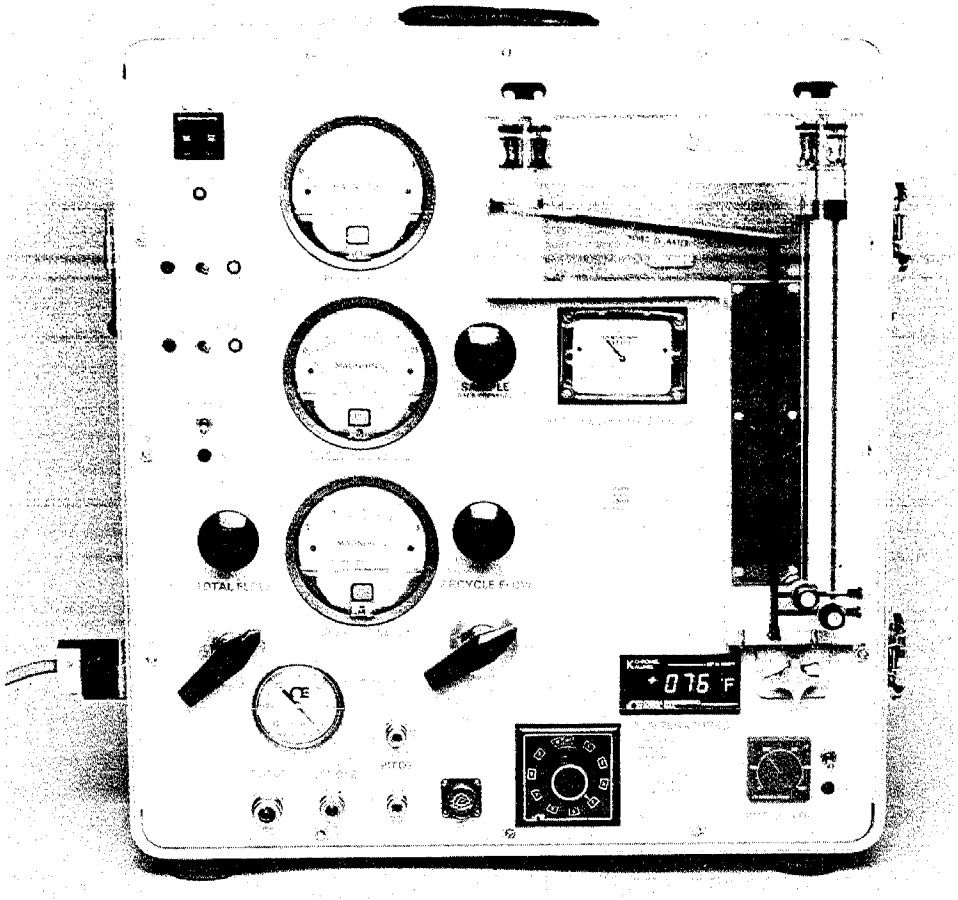

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Figure 3. EGR Sampling System Control Module (front view).

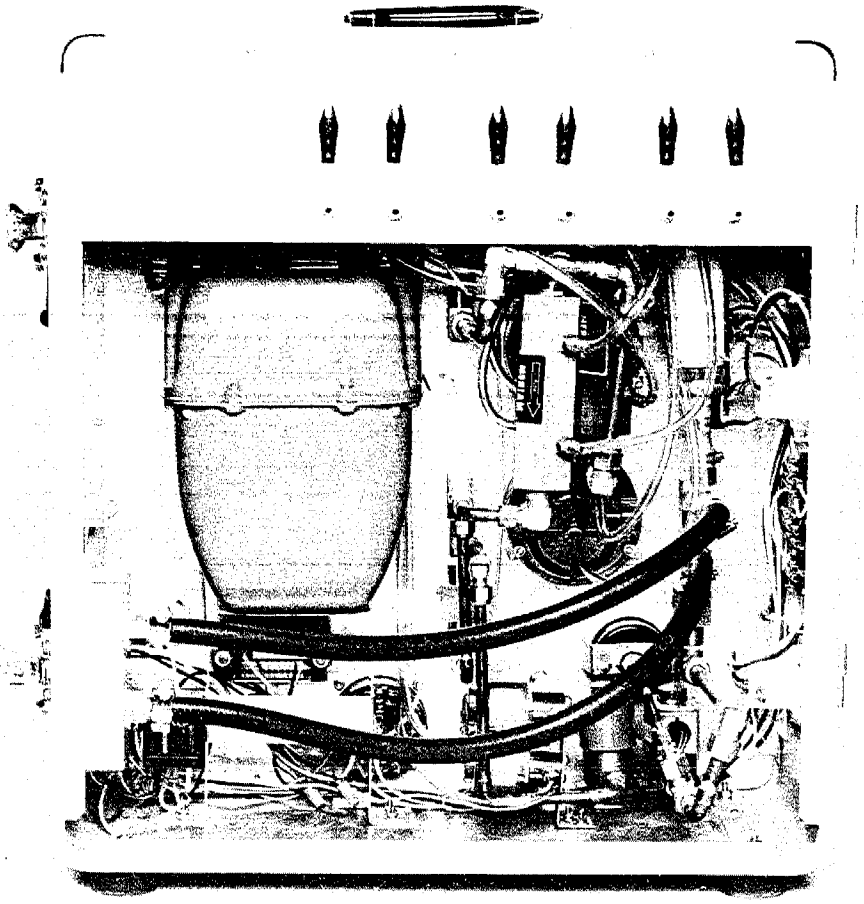

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Figure 4. EGR Sampling System Control Module (rear view).

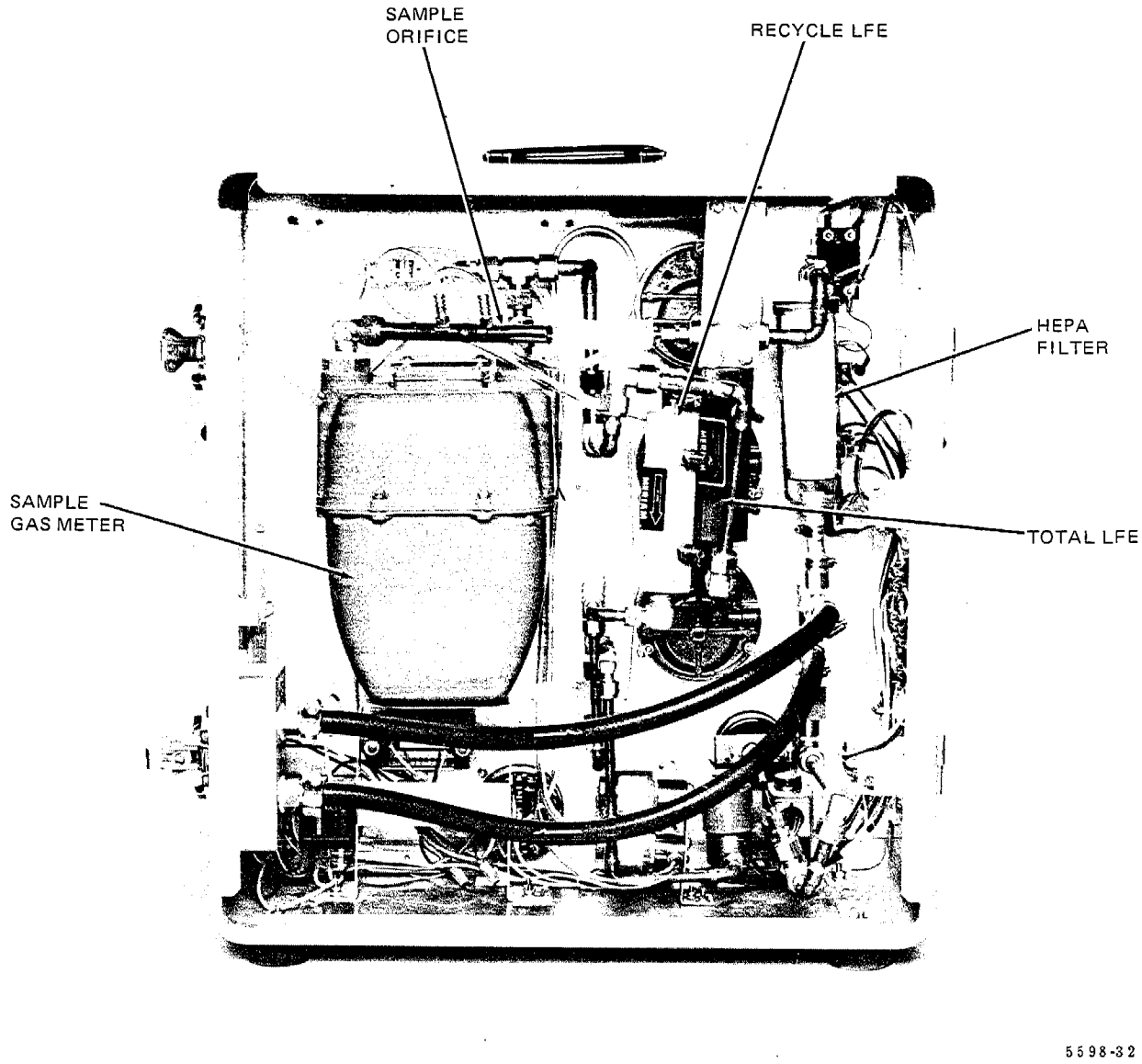

Figure 5. EGR Sampling System Control Module (rear view) showing internal components.

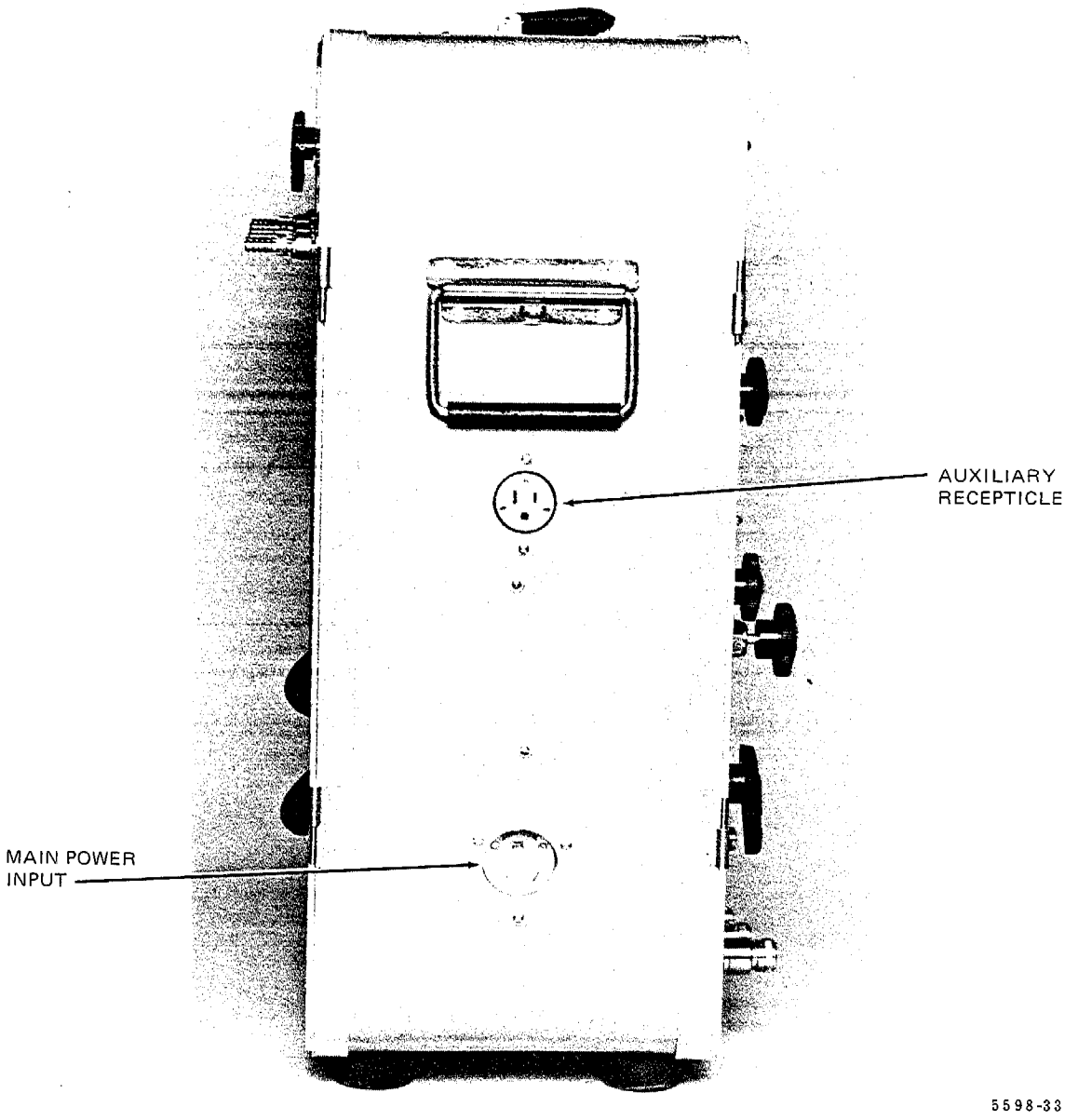

Figure 6. EGR Sampling System Control Module (right side).

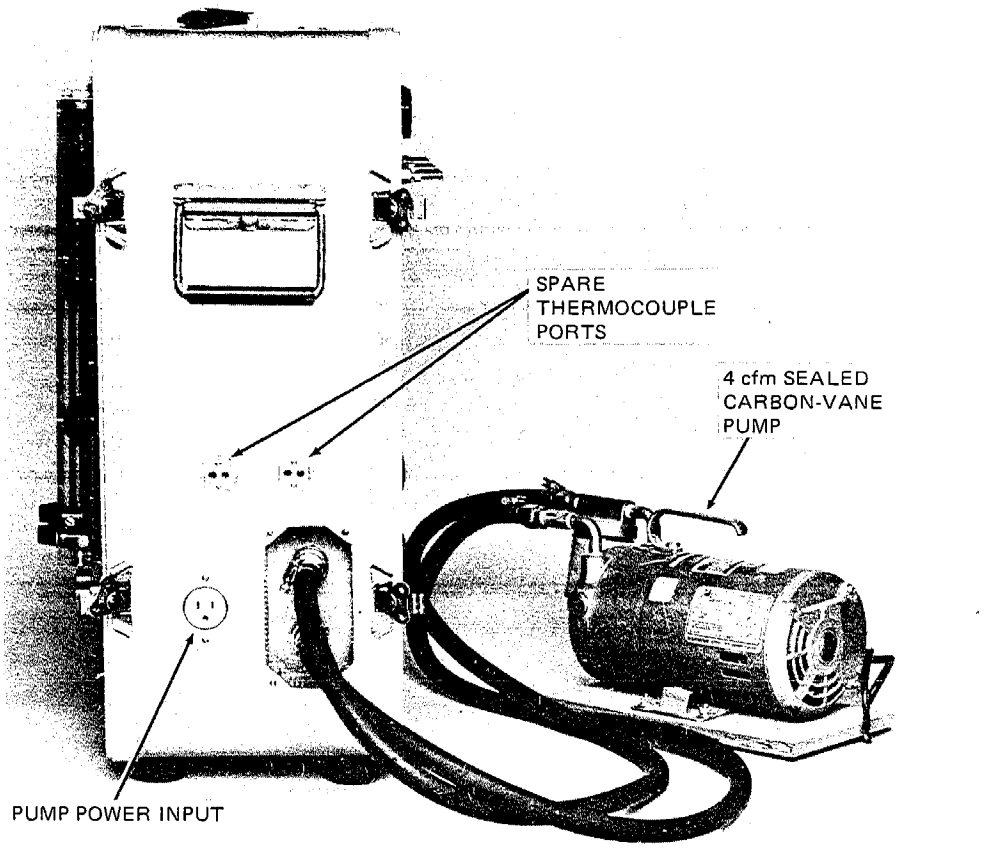

Figure 7. EGR Sampling System Control Module (left side) with 4 cfm pump.

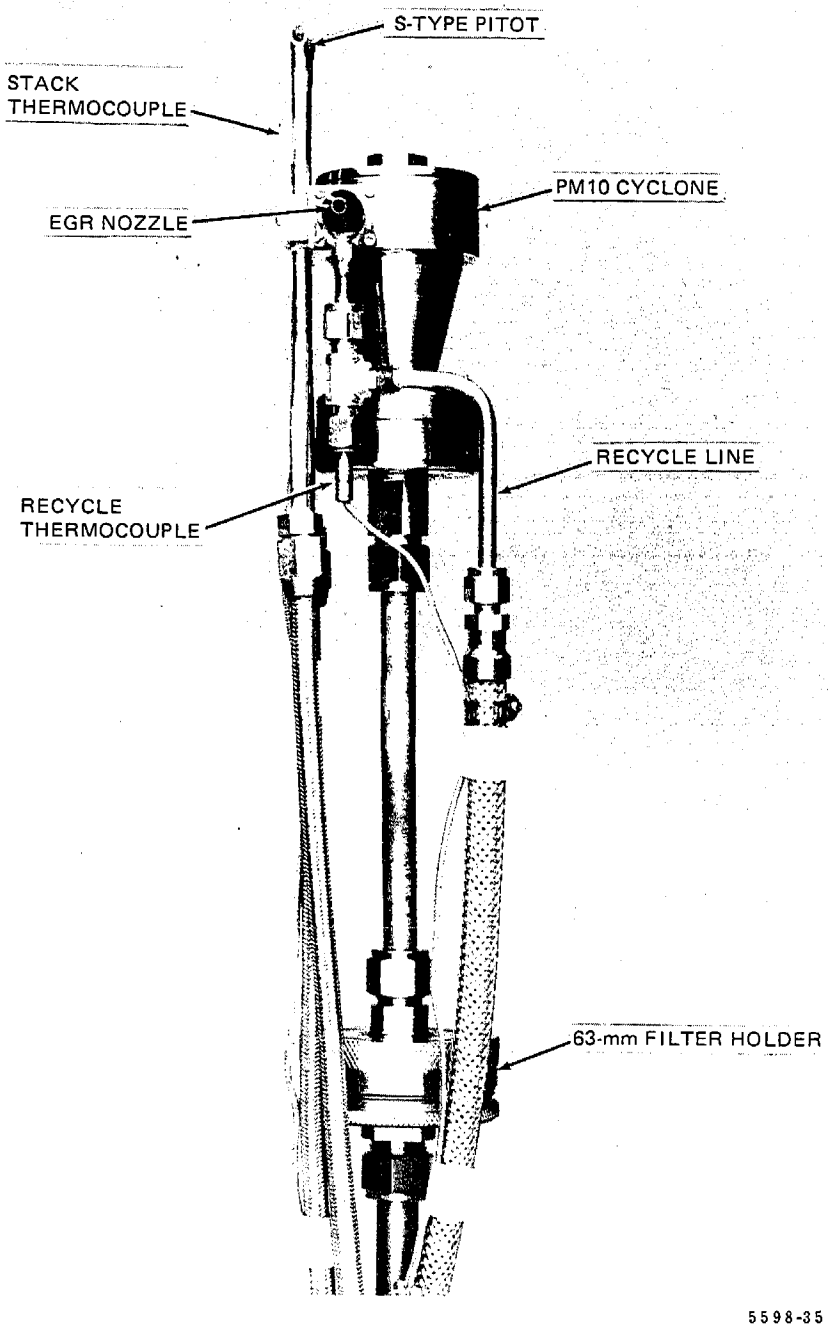

Figure 8. EGR PM10 Cyclone Sampling Device (front view).

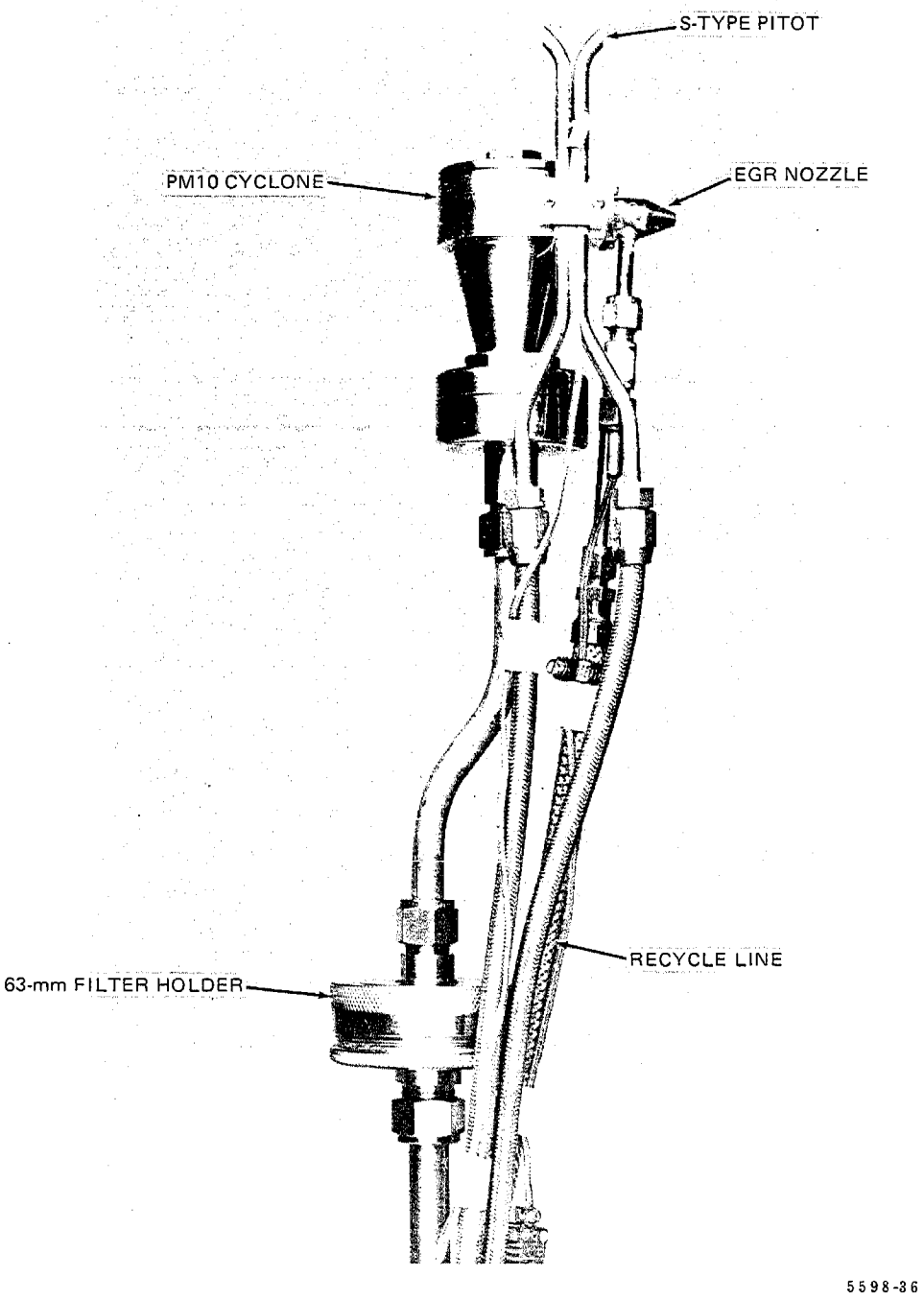

Figure 9. EGR PM10 Cyclone Sampling Device (front view).

The EGR sampling system as described above consists of an in-stack classifier and filter combination. In this configuration, its operation is analogous to Method 17 for total particulate emissions measurement. It should be noted, however, that system could be assembled to operate in a geometry similar to that of Method 5 sampling with the PM_{10} cyclone mounted directly onto the sampling probe and the filter mounted on the opposite end of the probe contained within an exterior oven. This mode would make it possible to maintain maximum similarity between the EGR sampling procedures and Method 5.

As mentioned previously, the specified PM_{10} classifier is part of a more complete size separation system. In some cases an additional (i.e. 2.5μm) size fraction may be desirable. The construction of the cyclone train allows mating between any combination of cyclones, as long as the cyclones are assembled in order of descending size. If additional cyclones are added to the system, extensions on the pitot and recycle lines may be required.

The remainder of this manual describes assembly, operation, and maintenance of the EGR sampling train. Assembly, the calculation of sampling parameters, and field operation are described in Sections 2 through 5. Data reduction is described in Section 6 and maintenance and calibration are described in Section 7. Quality Control check and procedures are outlined in Section 8. Section 9 describes results of calibration of the inertial size separation devices and Section 10 summarizes available field data comparing EGR to other techniques.

SECTION 2

FIELD ASSEMBLY

After the EGR sampling system has arrived at the test site it should be visually inspected to determine if any damage was incurred during transport. To check for internal probe damage, a positive pressure leak check on each of the four lines running through the probe is recommended. To do this, block one end of each line and apply positive pressure at the other. Monitor the pressure on the line with a manometer connected in parallel. Failure to hold pressure indicates an internal probe leak which should be found and repaired before proceeding.

If everything checks out, the operator should begin assembling the system. The chosen particle-sizing device should be assembled as its specific operating manual dictates. The EGR nozzle is then attached to the sampler, and the device is mounted on the probe, using tube unions, if necessary, to mount the sampler to the 5/8" sample line. The nozzle recycle line should be mounted to the temperature monitored 1/4" recycle line on the probe. Then using the proper length flexible extension tubes, the pitot head should be mounted on the probe. It is important to make sure the EGR sampling nozzle and one side of the pitot face the same direction as all the tubing unions are fully tightened. Latex or similar tubing can now be connected from the probe to the appropriate positions on the impingers and control box. If available, a combined umbilical is preferred. The recycle line should run directly from the probe to the control box. The sample line should be attached to the inlet of the water dropout system (impingers or condensers and silica gel column), which is, in turn, attached to the sample inlet of the control console.

It must be noted here that because it is important to know how much water is collected from the condensing system, all components of this system should be clean and free of any foreign material. If silica gel columns are used, a preweight of the column and silica gel should be obtained prior to any testing. Then the column must be sealed until testing commences to avoid any accidental uptake of moisture. After sampling the column will be weighed again to determine the amount of water uptake. If impingers or condensers are used, they should be placed in an ice chest, and ice added to the chest until the impingers or condensers are sufficiently covered. If impingers are used they should be preloaded with a measured quantity of distilled water.

The control module should be plugged into a normal household voltage outlet (120 V, 20 amps). Attach the multi-pin electrical/thermocouple connector at both the probe and the control box. The readouts of the thermocouples should be checked before proceeding to insure all are working properly. Check the manometer leads and make sure they are connected to the correct port and that each port is in the open position. With the hoses provided, attach the pump to the EGR control box. Plug the pump's power cord into the control box near the pump flow lines. At this point the EGR sampling system is fully assembled and ready for pre-sampling leak check.

SECTION 3

SAMPLING PARAMETERS

During a sample traverse, the operator must be able to convert the velocity pressure at a given point into the pressure differentials required across the flow orifice and recycle LFE to maintain isokinetic sampling and constant total flowrate, Q_t. With this goal in mind, the first step is the performance of a traverse to determine flue gas velocity, composition and temperature. Once the composition of the gas is known, molecular weight and viscosity can be determined. The viscosity of the gas is then used to calculate the relationship between flowrate and pressure drop for each LFE and orifice. With the velocity values obtained from the traverse, the operator can decide upon the remaining sampling parameters, such as inlet nozzle diameter and sampling time.

GAS VELOCITY AND ANALYSIS

A velocity traverse should be performed in accordance with EPA Reference Method 2.[5] The velocities, temperatures, and the static pressure in the flue should be measured. A gas analysis to determine the composition (molecular weight) of the flue gas, including the amount of water vapor, should be performed using the guidelines in EPA Reference Methods 3, 4, and others as necessary. For example, if there is a large amount of sulfuric acid in the flue, one would want to determine the percentage of H_2SO_4 present in the gas as vapor and the acid dew point by using EPA Reference Method 8.

The wet and dry mean molecular weights of the stack gas are needed for orifice, laminar flow element, and pitot calculations. For the accuracy needed in these calculations, the approximation is made that the only significant components of stack gas are O_2, CO_2, H_2O, N_2, and CO. Further, since CO has essentially the same molecular weight and approximately the same viscosity as N_2, the two gases are lumped together. Typically, oxygen and carbon dioxide concentrations are determined by Orsat or continuous monitors, and the balance of the dry gas composition is assumed to be nitrogen (or a combination of nitrogen and carbon monoxide). The dry gas mean molecular weight M_d is given by

$$M_d = 32\ f_{O_2} + 44\ f_{CO_2} + 28\ (1 - f_{O_2} - f_{CO_2}) \qquad (3\text{-}1)$$

where f_A is the volumetric or mole fraction of molecular species A.

The molecular weight of the wet stack gas is then given by

$$M_w = M_d\ (1-B_{wo}) + 18\ B_{wo} \qquad (3\text{-}2)$$

The ambient pressure (P_a, in. Hg) and stack pressure differential relative to ambient (ΔP_s, in. w.g.) are combined to calculate stack absolute pressure by the relation:

$$P_s = P_a + \Delta P_s/13.6, \quad (3\text{-}3)$$

where P_s is expressed in inches of mercury.

The viscosity of the flue gas can be determined by the equation (Williamson et al., 1983)[6]:

$$\mu = C_1 + C_2T + C_3T^2 + C_4f_{H_2O} + C_5f_{O_2} \quad (3\text{-}4)$$

where μ is in micropoise, T in °C, and

$C_1 = 160.62$
$C_2 = 0.42952$
$C_3 = 1.0483 \times 10^{-4}$
$C_4 = -74.143$
$C_5 = 53.147$

or for T in °R

$C_1 = 51.05$
$C_2 = 0.207$
$C_3 = 3.24 \times 10^{-5}$
$C_4 = -74.143$
$C_5 = 53.147$

This equation fits data (with a standard error of 0.98 micropoise) for a combustion gas of arbitrary composition in the range 0-350°C, 0-70% moisture. This equation was generated by SoRI personnel[6] from large "data banks" of viscosities calculated by the more rigorous algorithm of Wilke[7].

SAMPLING TIME

The sampling time required is set by the goals of the measurement effort. If the goal is to generate emissions factor data, then sufficient particulate matter in the PM_{10} fraction must be collected for accurate gravimetric analysis. If the goal is to obtain a PM_{10} sample for chemical analysis, the minimum amount of material to be collected is set by the requirements of the analytical laboratory. If the method is to be used as a compliance technique, a minimum sampled gas volume and/or dwell time per traverse point may be the determining factors.

The length of time required to collect an adequate sample is dependent upon the mass loading of the aerosol, the size distribution of the particles, and the flowrate of the sampler. If the results of a previous total mass test (Method 5 or 17) are available, the mass loading can be obtained from them. If not, an estimate should be made on the basis of the pre-test survey or other information. It must be kept in mind that the addition of recycle gas to the

sample gas in effect dilutes the particulate concentration of the gas through the particle sizing device. Therefore, in order to get an estimate of loading seen by the sizing device one must use the mean sample flowrate rather than the constant total flowrate through the inertial sizing device.

The sampling time is also dependent on the type of sizing device used. The nomograph in Figure 10 estimates the sampling time for a high capacity sampler, such as a PM_{10} cyclone, given a mass loading estimate. Results from initial tests can be used to more accurately establish the optimum sampling time. Due to physical characteristics, cyclones can inherently collect a large amount of particles without fear of bounce and re-entrainment. Cyclone catches may easily exceed 1 gm; the determining factor concerning loading limitations is whether or not re-entrainment occurs. In compliance or emissions factor measurement situations it is unlikely that a PM_{10} Cyclone will ever be overloaded at controlled sources if reasonable sampling durations are used.

SAMPLING TRAVERSE

In order to adequately characterize a given source, the complete traverse protocol should be successfully performed a minimum of three separate times, as is similarly called for by Method 5. If a sampling run is interrupted or declared invalid, the sampler should be cleaned, reassembled, and the test repeated.

Sampling should always be done traversing perpendicular to the flow of the stack gas. A vertical stack or duct requires a horizontal traverse. A horizontal duct may be traversed vertically or horizontally. When traversing vertically, it is preferable to traverse vertically down rather than vertically up because ports on the bottom side of the duct may emit accumulated particles. For stacks or ducts at offset angles, horizontal traversing is recommended. However, for round ducts this will not always be practical.

The number and placement of traverse points should be selected according to EPA Reference Method 1. For square or rectangular stacks, divide the duct cross-section into as many equal rectangular areas as sample points, such that the ratio of the length to the width of the elemental area is between one and two. In practice, however, the number and location of sampling ports does not always make this feasible and an adjustment must be made. In such a case, it is suggested that the tester sample as closely as possible to the location recommended by Method 1. The number of traverse points may also be increased beyond the number required by Method 1, keeping in mind that the sampling point matrix does not have to be balanced. Once the final matrix is decided upon, samples will then be taken at the centroids of each elemental area. For circular stacks, locate the sampling points on at least two diameters. Make sure

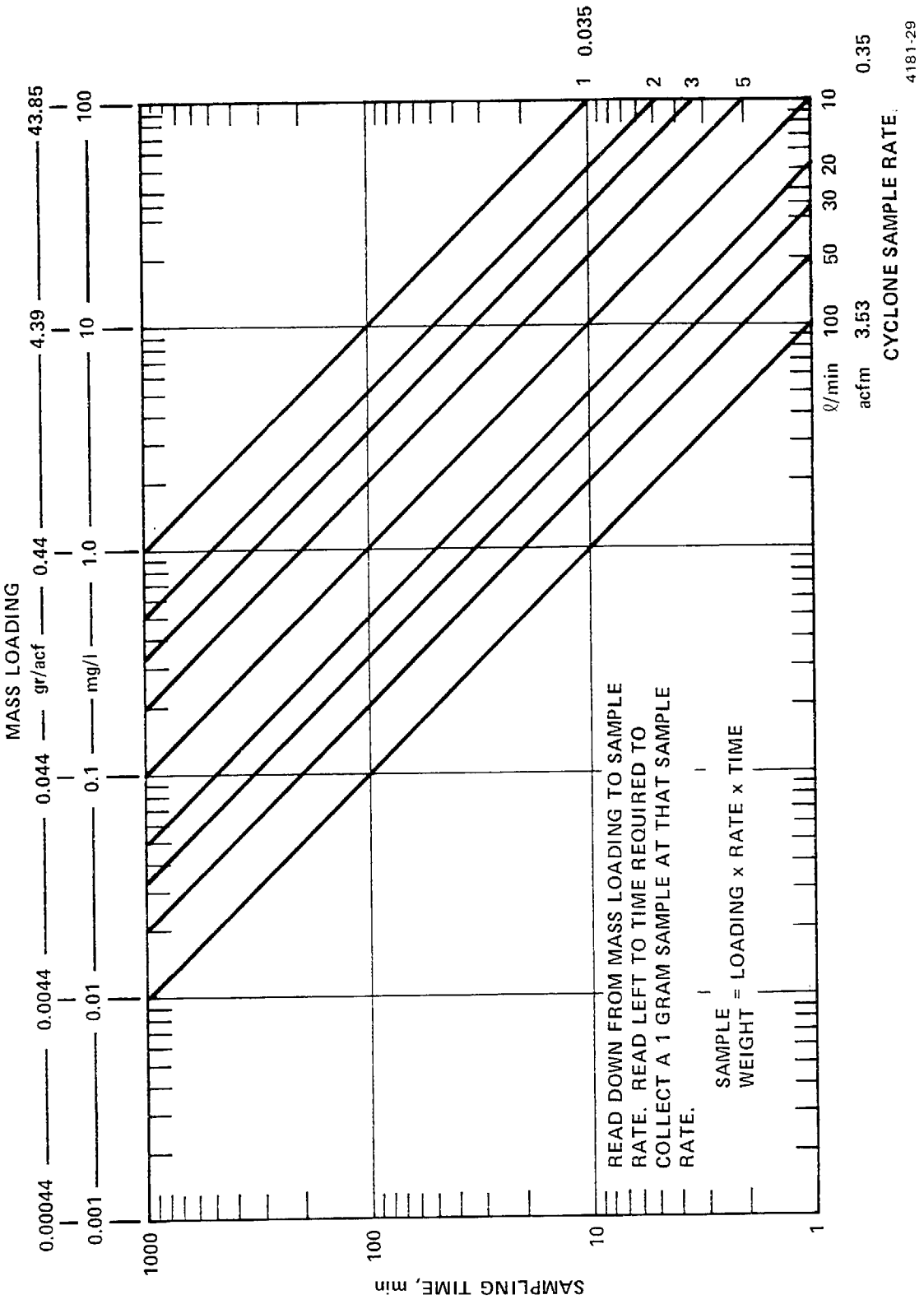

Figure 10. Nomograph for sampling time selection (Parsons and Felix, 1980).

that the traverse axes divide the stack cross-section into equal parts. Use Table I to determine the location of each sample point along the traverse of a circular duct.

It should be noted that when sampling the effluents from variable or cyclical processes, the test at each sampling point should extend through a complete cycle to insure that a representative sample is taken. This may not be practical and is commonly ignored in conventional source sampling procedures.

EGR SAMPLING FLOWRATES

To achieve isokinetic sampling the flowrate through the nozzle opening must produce a velocity equal to the local duct velocity. Furthermore, the flowrate through the size separating (PM_{10}) cyclone must be maintained at the flow required to produce a 10μm diameter cut to assure the integrity of the particle size fractionation. A correctly sized EGR nozzle will allow sampling (nozzle) flowrates to be set in the range from 20% to 90% of the total cyclone flowrate. The sample flowrate through the nozzle is determined from the nozzle diameter and the local stack velocity V:

$$Q_S = 0.3242\ d^2 V \qquad (3\text{-}5)$$

where V is expressed in ft/sec, d in inches, and Q_S in acfm.

This basic relationship assures an isokinetic target sample flowrate. Alternatively, the value of Q_S needed for isokinetic sampling can be determined from Method 5 nomographs once the nozzle diameter is known.

The total flow through the sampler is set according to the requirements of the sizing device. Normally, a 10μm cut will be desired and the required total sampler flowrate to obtain that cut will be found by using empirically determined calibration equations for the specific sampler. For example, if Cyclone I (of SoRI's Five-Stage Series Cyclone) is used as the particle separator, the required equation, based on currently available data, is

$$Q_{Cyc\ I} = .072962\ \left(\frac{M_w P}{T}\right)^{-0.2949}\ \mu\ D_{50}^{-1.4102} \qquad (3\text{-}6)$$

where D_{50} is the desired "cut-point" particle diameter in microns,
μ is the viscosity of the gas mixture in micropoise, and
$Q_{Cyc\ I}$ is the flow through the cyclone in acfm.
T is cyclone gas temperature in °R,
M_w wet molecular weight of mixed gas, and
P absolute stack pressure in inches of mercury.

Table 1. Location of Sampling Points in Circular Stacks (Percent of Stack Diameter from Inside Wall to Sampling Point).

Sampling Point Number On A Diameter	Number of sampling points on a diameter											
	2	4	6	8	10	12	14	16	18	20	22	24
1	14.6	6.7	4.4	3.3	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	85.4	25.0	14.7	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3		75.0	29.5	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4		93.3	70.5	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5			85.3	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6			95.6	80.6	65.8	35.5	26.9	22.0	18.8	16.5	14.6	13.2
7				89.5	77.4	64.5	36.6	28.3	23.6	20.4	18.0	16.1
8				96.7	85.4	65.0	63.4	37.5	29.6	25.0	21.8	19.4
9					91.8	82.3	73.1	62.5	38.2	30.6	26.1	23.0
10					97.5	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11						93.3	85.4	78.0	70.4	61.2	39.3	32.3
12						97.9	90.1	83.1	76.4	69.4	60.7	39.8
13							94.3	87.5	81.2	75.0	68.5	60.2
14							98.2	91.5	85.4	79.6	73.9	67.7
15								95.1	89.1	83.5	78.2	72.8
16								98.4	92.5	87.1	82.0	77.0
17									95.6	90.3	85.4	80.6
18									98.6	93.3	88.4	83.9
19										96.1	91.3	86.8
20										98.7	94.0	89.5
21											96.5	92.1
22											98.9	94.5
23												96.8
24												98.9

Specifically, for a D_{50} equal to 10μm, Equation 3-6 reduces to:

$$Q_{Cyc\ I} = 0.002837\ \left(\frac{M_w P}{T}\right)^{-0.2949}\ \mu\ \text{acfm}. \qquad (3\text{-}7)$$

For "first order" approximations the molecular weight and viscosity of the total cyclone gas may be calculated using actual stack gas conditions. However, as will be discussed in greater detail later, the addition of dry recycle gas decreases the overall moisture content of the gas to the cyclone. When a more exact PM_{10} flowrate is required, the actual moisture content must be determined as a function of the anticipated recycle gas fraction.

Unless the gas stream being sampled has a very low moisture content, the total flowrate required to maintain a fixed size cut will vary somewhat with the changes in the nozzle (sample) flow. And, unless the velocity distribution is very flat, and constant, the nozzle flow will have to be changed to maintain isokinetic sampling conditions. Thus the required total flow is not a constant but is a function of the nozzle flow. Because of the viscosity and molecular weight changes which take place with changes in the balance between the nozzle and recycle flow components of the total flow, the required total flow (and recycle flow) must be found by an iterative process as a function of the nozzle flow. The latter in turn is a function of the local flue gas velocity (or pitot ΔP).

Since the flow through the particle sizing device is the sum of the sample and recycle flows, the relationship can be expressed showing the recycle flowrate as a function of the sample flowrate. This is given by the equation

$$Q_T = Q_S + Q_R = XQ_S \qquad (3\text{-}8)$$

where Q_T is the total flow through the particle sizing device (acfm),
Q_S is the nozzle sample flowrate (acfm), and
Q_R is the recycle gas flowrate (acfm),
X is a variable representing the relationship between the recycle gas and sample flowrates (at X=1, Q_T=Q_S and Q_R=0).

The percent of the total gas mixture which is composed of the recycle gas can then be given by

$$PR = \left[\ 1 - \frac{Q_S}{Q_T}\ \right]\ (100\%). \qquad (3\text{-}9)$$

It has been concluded from laboratory experiments that if the recycle gas percentage exceeds 80%, the ability to obtain stable sample flows degenerates. Therefore, if the calculated recycle gas flow exceeds this limit, the chosen sample nozzle is too small and should be replaced with a larger one.

The addition of dry recycle gas to the sample gas in the EGR system decreases the moisture content of the gas mixture to the particle sizing device. This in turn changes the gas viscosity and molecular weight. With an initial value of percent recycle (PR) estimated, the water fraction of the mixture can be determined by

$$f_{H_2O} = B_{wo} \left(1 - \frac{PR}{100}\right) \quad (3\text{-}10)$$

where B_{wo} is the volumetric or mole fraction of water in the stack gas, and
f_{H_2O} is the water fraction of the mixture.

The viscosity and molecular weight of the mixture must now be calculated, using the previous equations (3-2 and 3-4), before the desired flowrate through the chosen particle-sizing device can be determined for a specific "cut-point". Using Equation 3-6, the required cyclone flowrate ($Q_{Cyc\ I}$) may in turn be calculated for Q_T. If a 10μm cut is sought, Equation 3-7 may be used instead to obtain Q_T.

If the desired sampler flowrate, Q_T, is less than the predetermined sample (through the nozzle) flowrate, Q_S, the sampling nozzle is too large and a nozzle with a smaller diameter should be substituted. If the total flowrate, Q_T, based on the moisture content of the stack/recycle gas mixture differs from the initial estimate of the required flow to obtain the desired size cut, $Q_{Cyc\ I}$, for a given sample flow by more than 1%, the equations must be reiterated. The variable "X" in the Equation 3-8 (shown below)

$$Q_T = XQ_S \quad (3\text{-}8)$$

is then changed to the ratio

$$X = Q_{Cyc\ I}/Q_S \quad (3\text{-}11)$$

Beginning with Equation 3-8, the parameters are then recalculated until the desired tolerance (1%) between the total and cyclone flowrates is attained. The 1% tolerance means that the D_{50} actually achieved will differ from the target by less than 1%. If a greater relative deviation from the target D_{50} can be permitted, the 1% tolerance can be relaxed somewhat. This would greatly reduce the computational time required for the setup calculations.

Since the recycle gas flowrate has been calculated as a percentage of the total sampler flowrate, it can be expressed by the equation

$$Q_R = Q_T\ (PR/100) \quad (3\text{-}12)$$

where Q_R is the recycle gas flowrate (acfm),
Q_T is the total flowrate through the sampler (acfm), and
PR is the percent recycle gas as compared to the total sampler flowrate.

Given the relationships shown in Equations 3-5 through 3-12, all the calculations necessary for nozzle selection and target flowrate determinations can be performed. The calculations of total flow, sample flow, and recycle flow must be made for each point of the sampling traverse.

Programs have been written in Apple basic computer language which perform the setup and data reduction calculations for the EGR train. The setup program calculates and prints a table of the necessary target readings for a range of flue gas temperatures and pitot ΔP readings based on expected minimum and maximum values of each parameter. The reduction programs calculate the

appropriate run parameters and particulate concentrations. The documentation for these programs is given in Appendices A and B.

Nozzle Selection

Ideally, the largest available EGR nozzle which is small enough to provide a sampling (nozzle) flowrate less than or equal to 90% of the total flowrate required for the desired size cut over the entire range of expected velocities should be used. Additionally, the chosen nozzle should not be operated at a flowrate below 20% of the total flowrate (80% recycle) as it becomes increasingly difficult to maintain stable flow conditions as the recycle percentage increases. In other words, at the maximum expected duct velocity (lowest recycle rate) the sample flowrate should be less than or equal to 90% of the total cyclone flowrate; and, at the lowest expected velocity (highest recycle rate) the sample flowrate should be greater than or equal to 20% of the total cyclone flowrate. This can be shown by the relationships

$$Q_S \leq 0.9\ Q_T \text{ for } V_{Max} \tag{3-13}$$

and

$$Q_S \geq 0.2 Q_T \text{ for } V_{Min}. \tag{3-14}$$

Substituting Equations 3-5 (Q_S) and 3-7 ($Q_{Cyc\ I}$ or Q_T), the above inequalities can be solved for the nozzle diameter (inches), as follows:

Solving the inequality shown in 3-13

$$0.3242\ D^2 V_{Max} \leq 0.002553\ \left(\frac{M_w P}{T}\right)^{-0.2949} \mu.$$

Solving for nozzle diameter (D)

$$D \leq 0.08874\ \left(\frac{M_w P}{T}\right)^{-0.1475} \left(\frac{\mu}{V_{Max}}\right)^{0.50} \text{ inches.} \tag{3-15}$$

Solving the inequality shown in 3-14 for nozzle diameter, similarly to that shown above

$$D \geq 0.04184\ \left(\frac{M_w P}{T}\right)^{-0.1475} \left(\frac{\mu}{V_{Min}}\right)^{0.5} \text{ inches.} \tag{3-16}$$

If a prospective nozzle diameter satisfies both the inequalities shown (3-15 and 3-16), the nozzle could be successfully used across the expected traverse. Should more than one available nozzle diameter satisfy the above criteria, it is recommended that the larger of the nozzles be used, as this would require less recycle gas. It should be noted for the purpose of manually calculated nozzle selection, the iterative process described previously may not be necessary. A first order approximation of the cyclone gas viscosity and molecular weight, using the stack gas moisture (see Equations 3-2 and 3-4), may be sufficient. However, the computer programs which have been written to perform the nozzle selection performs the aforementioned iterations. Further, the nozzle selection portion of the setup program uses the average duct velocity as opposed to the maximum and minimum velocities.

Target Pressure Differentials (ΔH, ΔP_T, and ΔP_R)

At each expected traverse point, the target pressure differentials for each of the flow metering devices (sample orifice, total flow LFE, and recycle flow LFE) must be calculated as function of the local stream velocity and temperature. The desired flowrates at each traverse point can be determined using Equations 3-1 through 3-12. After the three target flowrates (Q_S, Q_T, Q_R) have been calculated for a given traverse point, the settings for the flow metering devices can be determined. For the purpose of these calculations the sample flow meter is assumed to be an orifice meter for which the flow is governed by the equation

$$Q = (.9615/\sqrt{\Delta H@}) * (\Delta HT/P(M_d)^{0.5} \qquad (3\text{-}17)$$

The calibration factor $\Delta H@$ is defined as the pressure drop across an orifice which produces a flowrate of 0.75 cubic feet per minute at standard conditions (528°R and 29.92 in Hg). Because of the lower flowrate at which the PM_{10} sampler operates as compared to Method 5, the orifice meter used for Method 5 train is not appropriately sized for PM_{10} sampling. The $\Delta H@$ value of the PM_{10} orifice is obtained by calibration as outlined in Method 5. For the present calculations, Q is expressed in actual cubic feet per minute at orifice conditions, T in °R, P in inches of mercury, and ΔH in inches water gauge. M_d is inherently dimensionless, and equals 28.97 for standard air.

Using the above formalism and typical ideal gas law calculations, the desired readings at the sample flow orifice can be calculated. For the equations that follow, variables subscripted with "s" refer to stack conditions, and the subscripts "a" and "m" refer to ambient and meter conditions, respectively. The ΔH target for the desired flow is given by

$$\Delta H = \frac{M_d T_m \Delta H@}{P_m} \left(\frac{Q_s \, P_s \, (1-B_{wo})}{.9615 \, T_s} \right)^2. \qquad (3\text{-}18)$$

In this equation correction is made in the conventional manner for the uptake of moisture in the condenser and drying column or impinger train.

The flow behavior of the laminar flow elements (for total and recycle flowrates) can be shown by the equation:

$$Q_{LFE} = M\Delta P(\mu_{STD}/\mu_{LFE}) + B \qquad (3\text{-}19)$$

Q_{LFE} = flowrate at LFE (acfm),
M, B = linear fit calibration coefficients,
ΔP_m = LFE pressure differential (in $H_2 0$),
μ_{STD} = viscosity of standard air (180.1 micropoise), and
μ_{LFE} = viscosity of gas through LFE (micropoise).

Since the absolute pressure at the inlets to the recycle and total flow LFE's is typically higher than ambient, the difference cannot be ignored when converting from meter flowrates to flowrates at stack conditions. Laboratory and field testing have indicated an average difference to ambient of eight inches water gauge at the inlet to these devices. For the purpose of setup equations, the absolute pressure at devices is given by the equation:

$$P_m = P_a + 8.0/13.6$$

$$P_m = P_a + 0.588 \ . \qquad (3\text{-}20)$$

Therefore, the target pressure differential for the total flow LFE can be given by the equation

$$\Delta P_T = (\mu_{LFE}/\mu_{STD}) \left[Q_T P_s T_m/(P_m T_s(1 - f_{H_2O})) - B_T\right]/M_T. \qquad (3\text{-}21)$$

It should be noted that f_{H_2O} represents the water content of the mixed (cyclone) gas and not the stack gas.

Since the recycle gas theoretically contains no moisture at either the LFE or the cyclone (stack) the equation for the target ΔP recycle becomes:

$$\Delta P_R = (\mu_{LFE}/\mu_{STD}) \left((Q_R P_s T_m/P_m T_s) - B_R\right)/M_R. \qquad (3\text{-}22)$$

If desired, the time per revolution of the EGR sample dry gas meter is given by

$$t(\text{sec/rev}) = 6/(Q_{DGM}\gamma) \qquad (3\text{-}23)$$

where $Q_{DGM} = (Q_{SAM_s} \ P_s/T_s) \ (1 - B_{wo}) \ (T_m/P_a)$, and

γ = is the correction factor for a 0.1 cubic foot per revolution gas meter.

As mentioned previously, the EGR setup computer program produces a table of target pressure differentials (ΔH, ΔP_T, and ΔP_R) as a function of a given range of temperatures and velocities. In practice, the operator would locate the intersection of the appropriate temperature (top of table) and the observed velocity head (left side of table). At this point the operator would note the desired target values and adjust the system accordingly.

SAMPLE CALCULATIONS FOR NOZZLE SELECTION AND TARGET PARAMETERS

Using the sample setup parameters shown in Table 2, the nozzle selection will be made and target flow metering pressure differentials will be calculated for one traverse point. The values used from Table 2 were also used to generate a "run table" using the computer setup program described in Appendix A (computer program EGR SETUP 3.1). It should be noted the small differences between the values manually calculated below and those generated by the computer can be attributed to round off error.

The relationships shown in Equations 3-15 and 3-16 must be satisfied if the candidate EGR nozzle is to be successfully used.

$$D \leq 0.08874 \left(\frac{M_w P}{T}\right)^{-0.1475} \left(\frac{\mu}{V_{Max}}\right)^{0.50} \qquad (3\text{-}15)$$

Table 2. Sample Setup Parameters

P_{BAR}:	30.02 inches Hg	T_{Meter}:	70°F
ΔP_{STK}:	0.0 inches H_2O		
$T_{STK(Max)}$:	350°F	$V_{STK(Max)}$:	45 ft/sec
$T_{STK(Avg)}$:	310°F	$V_{STK(Avg)}$:	37 ft/sec
$T_{STK(Min)}$:	250°F	$V_{STK(Min)}$:	30 ft/sec

Gas Composition

H_2O:	16%
O_2 :	6%
CO_2:	12%

Available Nozzle Diameters

D_1:	0.1193 inches
D_2:	0.1853 inches
D_3:	0.2477 inches

Calibration Values

C_p(Pitot):	0.83
$\Delta H@$(Orifice):	10.980
M_T(Total LFE):	0.2298
B_T(Total LFE):	-0.0058
M_R(Recycle LFE):	0.0948
B_R(Recycle LFE):	-0.0007
γ(Dry Gas Meter):	0.9940

and

$$D \geq 0.04184 \left(\frac{M_w P}{T}\right)^{-0.1475} \left(\frac{\mu}{V_{Min}}\right)^{0.5} . \qquad (3\text{-}16)$$

As can be seen, the viscosity and wet molecular weight of the sample must be determined before the above inequalities may be solved. The wet molecular weight may be found using Equations 3-1 and 3-2, as follows:

$$M_d = 32f_{O_2} + 44f_{CO_2} + 28\ (1 - f_{O_2} - f_{CO_2}) \qquad (3\text{-}1)$$

$$= 32(0.06) + 44(0.12) + 28(1 - 0.06 - 0.12)$$

$$= 30.16$$

and

$$M_w = M_d(1 - B_{wo}) + 18\ B_{wo} \qquad (3\text{-}2)$$

$$= 30.16(1 - 0.16) + 18(0.16)$$

$$= 28.21.$$

The viscosity may be found by the relationship shown in Equation 3-4

$$\mu = 51.05 + 0.207(T) + (3.24 \times 10^{-5})(T^2) - 74.143(f_{H_2O}) + 53.147(f_{O_2}) \qquad (3\text{-}4)$$

$$= 51.05 + 0.207(770) + (3.24 \times 10^{-5})(770^2) - (74.143)(0.16) + (53.147)(0.06)$$

$$= 220.98 \text{ micropoise.}$$

The previous inequalities may now be solved

$$D \leq 0.08874 \left(\frac{28.21(30.02 + \frac{0.0}{13.5})}{770}\right)^{-0.1475} \left(\frac{220.98}{45}\right)^{0.50}$$

$$D \leq 0.1939 \text{ inches}$$

and

$$D \geq 0.04184 \left(\frac{28.21(30.02 + \frac{0.0}{13.6})}{770}\right)^{-0.1475} \left(\frac{220.98}{30}\right)^{0.5}$$

$$D \geq 0.1120 \text{ inches.}$$

Therefore, in this case, the desired nozzle must satisfy the relationship $0.1120 \leq D_n \leq 0.1939$. Tables 2 shows both nozzles D_1 and D_2 (0.1193" and 0.1853", respectively) would fulfill this requirement. However, as previously recommended, it is desirable to use the nozzle which will produce the lower recycle ratios. Therefore, nozzle D_2 (diameter = 0.1853") would be selected.

In practice, the operator would need to determine target pressure differentials for each of the three measured flowrates (sample, total, and recycle) at each expected sampling location. As the stack conditions (specifically, local velocity and temperature) change from point-to-point, the target ΔH (or ΔP) would also change accordingly. Ideally, the operator would have a set of target values for each point. A more practical approach was taken with the computer program (Appendix A) developed for these calculations. The program calculates the target pressure differentials for an input range of temperatures and velocities (expressed in terms of pitot pressure head) and generates a row-column look-up table with columns representing entries for gas temperatures in the appropriate range and row representing pitot pressure differentials. Target values for the flow meter pressure differentials are provided at each row/column intersection.

For the purpose of these sample calculations only one set of target values will be determined. For comparison with the computer generated table, (see Appendix A) the temperature at the selected sampling point will be assumed to be 306°F and the velocity head (ΔP_{PTO}) will be assumed equal to 0.31 inches H_2O.

Using the stack (wet) molecular weight calculated previously, the local stack gas velocity may be found using the standard equation from EPA Reference Method 2:

$$V = 85.48\ (C_p)\ \sqrt{\Delta P}\ \left(\frac{T_s}{P_s M_s}\right)^{0.5}$$

$$= 85.48\ (0.83)\ \sqrt{0.31}\ \left[\ \frac{(460 + 306)}{(30.02 + \frac{0.0}{13.6})\ 28.21}\ \right]^{0.5}$$

$$= 37.57 \text{ ft/sec.}$$

The isokinetic sample (nozzle) flowrate may now be found using Equation 3-5:

$$Q_s = 0.3242\ d^2\ V \qquad (3\text{-}5)$$

$$= 0.3242\ (0.1853)^2\ (37.57)$$

$$= 0.4182 \text{ acfm (at stack conditions).}$$

The "first guess" cyclone flowrate for a PM_{10} cut can be found using Equation 3-7, and the previously determined stack gas molecular weight (wet) and viscosity as estimates for the values of the mixed sample and recycle flows.

$$Q_{Cyc\ I} = 0.002837\ \left(\frac{M_w P}{T}\right)^{-0.2949}\ \mu \qquad (3\text{-}7)$$

$$= 0.002837\ \left(\frac{28.219(30.02 + \frac{0.0}{13.6})}{766}\right)^{-0.2949}(220.98)$$

$$= 0.6086 \text{ acfm (at stack conditions).}$$

Next, the "total" flowrate must be calculated as a function of the sample flow from Equation 3-8:

$$Q_T = XQ_S \tag{3-8}$$

$$Q_T = 1\ (Q_S)$$

$$= 0.4182 \text{ acfm.}$$

Using $Q_{Cyc\ I}$ as an estimate of Q_T, we have:

$$X = \frac{Q_T}{Q_S} = \frac{Q_{Cyc\ I}}{Q_S} \tag{3-11}$$

$$= \frac{0.6086}{0.4182}$$

$$= 1.4553.$$

The approximate percent recycle (Equation 3-9) is thus

$$PR = (1 - \frac{0.4182}{0.6086}) \times 100\% \tag{3-9}$$

$$= 31.3\%.$$

The moisture fraction of the combined (cyclone) gas is thus estimated as

$$f_{H_2O} = 0.16\ (1 - \frac{31.3}{100}) \tag{3-10}$$

$$= 0.11 \text{ or } 11\%.$$

The next step is to determine the cyclone PM_{10}, flowrate as a function of the newly calculated combined gas composition. Therefore, the wet molecular weight and viscosity (using Equations 3-2 and 3-4) will also have to be redefined. The dry molecular weight remains unchanged so

$$M_W = 30.16\ (1 - 0.11) + 18\ (0.11) \tag{3-2}$$

$$= 28.82$$

and

$$\mu = 51.05 + .207(766) + (3.24\text{x}10^{-5})(766^2) - 74.143(0.11) + 53.147(.06) \tag{3-4}$$

$$= 223.66 \text{ micropoise.}$$

Now, $Q_{Cyc\ I}$ for a 10μm cut may be recalculated and

$$Q_{Cyc\ I} = 0.002837 \left(\frac{28.82\ (30.02 + \frac{0.0}{13.6})}{766}\right)^{-0.2949}\ (223.66)$$

$$= 0.6121 \text{ acfm.}$$

$Q_{Cyc\ I}$ and Q_T may now be compared to determine the percent difference

$$\text{Difference} = \left(\frac{0.6121 - 0.6086}{0.6121}\right) \times 100\%$$

$$= 0.57\%.$$

The required percent recycle is now

$$PR = \left(1 - \frac{0.4182}{0.6121}\right) \times 100$$

$$= 31.7\%$$

Since the tolerance limit of ±1.0 has been satisfied, the recycle flowrate required for the given conditions may now be calculated using Equation 3-12:

$$Q_R = Q_{Cyc\ I} \left(\frac{PR}{100}\right)$$

$$= 0.6121 \left(\frac{31.7}{100}\right)$$

$$= 0.1940 \text{ acfm.}$$

Had the revised total flow estimate differed by more than 1% from the initial guess, a second round of calculations would have been needed. The latter is likely to be the case only if the moisture content of the stack gas is quite high and a high recycle rate is needed.

The target pressure differentials for the sample orifice, total LFE, and recycle LFE, can now be calculated using Equations 3-18 through 3-22.

From Equation 3-18, the target orifice differential pressure may be determined as follows:

$$\Delta H = \frac{M_d T_m \Delta H@}{P_m} \left(\frac{Q_S P_S (1 - B_{wo})}{0.9615\ T_s}\right)^2 \qquad (3\text{-}18)$$

$$= \frac{(30.16)(530)(10.980)}{30.02} \left(\frac{(0.4182)(30.02 + \frac{0.0}{13.6})(1 - 0.16)}{0.9615(766)}\right)^2$$

$$= 1.19 \text{ inches } H_2O.$$

The target ΔP_T (total LFE) may be found from Equation 3-21:

$$\Delta P_T = \left(\frac{\mu_{LFE}}{\mu_{STD}}\right) \left[\left(\frac{Q_T P_S T_m}{P_m T_s}\right)(1 - f_{H_2O}) - B_T\right] \left(\frac{1}{M_T}\right). \qquad (3\text{-}21)$$

As can be seen, the viscosity at the LFE must be determined before the ΔP_T can be found. Using the anticipated meter box temperature (70°F) and assuming the moisture content of the gas and time control console equal to zero Equation 3-4 can be used as shown:

$$\mu_{LFE} = 51.05 + .207(530) + 3.24\times10^{-5}(530^2) - 74.143(0.0) + 53.147(0.06) \quad (3\text{-}4)$$

$$= 173.05 \text{ micropoise.}$$

Therefore,

$$\Delta P_T = \left(\frac{173.05}{180.1}\right)\left[\frac{(0.6121)\left(30.02+\frac{0.0}{13.6}\right)(530)}{(30.02+0.588)(766)}(1-0.11) + 0.0058\right]\left(\frac{1}{0.2298}\right)$$

$$= 1.57 \text{ inches } H_2O.$$

By using the appropriate flowrate and calibration values, the target ΔP_a for the recycle LFE may be determined using Equation 3-22. However, it must be noted the recycle fraction makes no correction for moisture content.

$$\Delta P_R = \left(\frac{173.05}{180.1}\right)\left[\frac{(0.1940)\left(30.02+\frac{0.0}{13.6}\right)(530)}{(30.02+0.588)(766)} + 0.0007\right]\left(\frac{1}{0.0948}\right)$$

$$= 1.34 \text{ inches } H_2O.$$

If desired, the time per revolution of the dry gas meter needle for a given sample flowrate may be determined using Equation 3-23:

$$t = \frac{6\ T_s P_a}{Q_{SAM_s}\ P_s T_m (1 - B_{wo})\gamma} \quad (3\text{-}23)$$

$$= \frac{6(460+306)(30.02)}{(0.4182)\left(30.02+\frac{0.0}{13.6}\right)(460+70)(1-0.16)(0.9440)}$$

$$= 24.8 \text{ sec/rev.}$$

These calculations would have to be repeated for each point of the sampling traverse for which either the flue gas temperature or the pitot velocity pressure differs from the values for the example. Doing the calculations by hand is possible but laborious and it would probably be more satisfactory to setup a programmable calculator to do them or to use the BASIC computer program "EGR SETUP 3.1" given as part of Appendix A.

SECTION 4

TAKING THE SAMPLE

LEAK TEST

The sampler, probe, condensers, and sampling lines should have been leak-checked prior to final assembly by pressurization and testing for holding a positive pressure in the devices. This can be achieved by plugging one end of the line to be tested and applying a positive pressure at the opposite end. By placing a pressure gauge in parallel with the test line the pressure within the system can be monitored. If the system fails to maintain pressure after it is sealed, a soap solution can be used to locate leaks.

Leaks within the sampling device, probe, or condensers may be found using the EGR control console pump as in a Method 5 leak check. Plug the sampling nozzle, turn the recycle gas valves completely off, and turn on the EGR pump to produce a vacuum across the desired test section. Use the total flow fine adjust valve to set the system vacuum to 15 inches of mercury. If the required vacuum reading on the console mounted vacuum gauge cannot be achieved or if the gas meter indicates a flowrate greater than 0.02 cubic feet per minute, the system is not sealed and the leak(s) must be located and fixed.

The positive pressure portion of the control console can be tested for leaks in a similar manner or using the procedure in Method 5. Using an auxillary pump/DGM system (or spare sampling system), attach the recycle output of the EGR system, using latex or similar tubing, to the input of the auxilary system. Completely open the recycle valves and close the total flow and sample back-pressure valves. Continue the procedure as outlined above. The same limits (leak rate $\leq$ 0.02 cfm) apply to the positive side of system as the negative side. An alternate method for the positive side of the EGR system would be to completely close the recycle valve, plug the sample inlet, and attach a short section of tubing to the outlet of the flow orifice. Vent the low side of the orifice manometer to ambient pressure and plug the corresponding pressure tap on the orifice. Pressurize the system to 5 to 10 inches of water, then pinch off the tubing. If the manometer fails to hold pressure, a leak is present in the system. Parts to check are the pump, tube fittings, valves, and tubing.

PRETEST EQUIPMENT WARMUP

Since most flue streams to be tested are not at ambient temperatures, the EGR sampling train must be heated to stack conditions. This helps insure isokinetic sampling, significantly reduces the chance of acid deposition within the sample line, and allows isothermal introduction of recycle gas at the inlet of the particle sizing device. This is accomplished through the use of the heated EGR probe and in-the-flue-heating of the sampler.

The sampler should be heated in the flue long enough to equilibrate. Typically, the PM_{10} Cyclone I/filter combination should remain in the flue at least 15-20 minutes to insure thermal equilibrium. The nozzle, if uncapped, should not point into the flow field during preheating. If possible, the nozzle should be capped or plugged during preheating, and the cap or plug removed immediately before sampling. The probe temperature is regulated by a proportional temperature controller set approximately equal to the stack temperature. While the sampling device is heating in the flue, the probe heater controller should be adusted to heat the recycle line to stack temperature. When condensible vapors are present, the probe should be heated to and maintained above the dew point. Care should be taken to insure that vapor does not condense in the portion of the probe extending outside the flue and flow back into the sampler.

FLOWRATES

As stated previously, the flowrate through the sampling nozzle is directly dependent on the stack gas velocity at the sample point. In operation, therefore, the pressure differential, ΔH, of the sample orifice meter is adjusted according to the previously determined run calculations with shifts in the ΔP_{pitot} readings. This insures continued isokinetic sampling. This in turn means the flowrate of the recycle gas must also be adjusted to maintain the proper total flow through the particle sizing device. During startup the operator initially sets the total sampler flowrate using valves V_1 and V_2. After setting the approximate total flowrate, the sample flowrate is set by adjusting the recycle valves V_3 and V_4. If high recycle ratios are required, V_5 may need to be adjusted. The operator should check to be sure the recycle flowrate is now properly set. Because there is some interaction between flowrates, a few minor repeat adjustments may be required between the total and sample flowrates. Typically, when traversing to another sampling point, only the fine recycle adjust (V_4)or the sample back pressure valve (V_5) will need adjustment. These point-to-point adjustments may require slight adjustment to the total flow. If so, repeat the iterative process outlined above until the target ΔP_T and ΔH sample values are achieved. Again, the recycle flowrate should be used as a "check" of the other flowrates. The practiced operator can usually obtain the target values within one or two iterations at each new point.

TRAVERSING

During traversing (moving to a new point or new port) all motion should be smooth and brief to avoid bumping or vibrating the sampler. When removing or inserting the sampler, care must be taken not to scrape the nozzle on the port wall. Also, the sampler should not be allowed to bump against the far inside wall of the flue.

SHUTDOWN ORIENTATION

Depending on the orientation of the sampler, it may be advisable to maintain an appreciable flowrate while removing the sampler from the flue. The flowrate should be maintained until the sampler can be placed in a favorable orientation (usually horizontal). This is particularly true when operating a cyclone in a vertical orientation. Otherwise some dust might fall from one stage of the sampler to another and thus be measured where it was not collected. After the flow has been terminated, the sampler can be transported to the lab. It should be kept in a horizontal position with the nozzle plugged or covered to avoid contamination or loss of sample.

DATA LOGGING

The parameters of the test should be recorded in a clear, concise format like that shown in Figure 11. Parameters that are likely to change, such as sample and recycle gas flowrates, should be recorded periodically. Other examples are port number, traverse point, gas meter temperature, gas meter volume, metering orifice and LFE pressure drops, atmospheric pressure, stack gas temperature, etc.

Run Code	Date	Stack Temperature (°F)	Gas Composition $\%CO_2$ $\%O_2$ $\%CO$
Sampler ID	Start Time	Differential Stack Pressure (in.H_2O)	Moisture Content
Filter ID	End Time	Ambient Temperature (°F)	
Sampler Orientation	Sampling Duration (min)	Ambient Pressure (in.Hg)	
Sampling Location	DGM (initial)	Gas Velocity	Pitot Leak Check (Pos) (Neg)
Nozzle Diameter-ID (in)	DGM (final)	System Leak Check	Notes
Operator(s)	Sample Volume (ft^3)		
Dual Manometer Leveled and Zeroed?			
Magnehelics Zeroed?			

Run Time	Port No Trav.Pt.	ΔP Pitot	ΔH Sample	DGM Volume	ΔP Total	P Inlet	ΔP Recycle	T_1 Stack	T_2 Recycle	T_3 Probe	T_4 LFE	T_5 DGM

Figure 11. Suggested EGR Runsheet.

SECTION 5

SAMPLE RETRIEVAL AND WEIGHING

UNLOADING THE SAMPLER

After the sampler has cooled down to nearly ambient temperature and been brought into the lab, it should be carefully "unloaded." Unloading consists of removing the particulate mass caught in the sampler. Great care is needed in this procedure to insure that all of the particulate matter is recovered and placed in the proper sample containers. The sample can be effectively recovered using a combination of brushing and washing. The particulate should be brushed into a uniquely identified, preweighed sample container for each stage of the sampler. A No. 7 camels hair brush or small nylon bristle brush is suggested for this operation. After the brushing is completed the same surface should be washed with a reagent grade solvent, such as methylene chloride, into a preweighed bottle or aluminum cup. The sample wash should be allowed to completely evaporate before desiccation and weighing. The mass gained for each stage (PM_{10} cyclone and filter) is the sum of the appropriate brushed recovery and wash residue.

Particulate matter collected from the inner surfaces of the EGR nozzle, the cyclone body, collection cup and cap are to be considered as collected by the cyclone. Furthermore, any matter brushed or rinsed from the outside of the cyclone exit tube is also to be considered part of the cyclone catch. The PM_{10} fraction, if that was the size fractionation achieved, consists of particulate matter collected from the inner surface of the "turn-around" on the cyclone cap, the inside wall of the exit tube, the inner walls of the filter holder (upstream of the filter), and the surface of the filter. Also, if the system was operated in a Method 5 geometry, the wash from the probe is to be included in the PM_{10} fraction. In some circumstances, the residue from the condensers or impingers may be considered to be PM_{10} condensables.

DRYING AND WEIGHING

Each of the particulate containers must be dried to a constant weight, with two hour checks used to establish the uniformity of the weights. Hard, non-volatile particles are often dried in a convection oven at a temperature of 212°F, desiccated until cooled to room temperature, weighed, and then check-weighed two hours later. Volatile particles present special problems which have to be dealt with according to the particulate characteristics and sampling goals. One technique for particles which are volatile at elevated temperatures is to desiccate them 24 hours before weighing. Whatever the technique used, constant weight of the samples after further drying is the criterion to be met. The results of the weighings and any notes should be recorded in a notebook with which the run sheets are kept.

One method of insuring dry sample weights for hygroscopic samples was developed by SoRI personnel using polyethylene glove bags to provide an enclosed, dry atmosphere. Instruments for Research and Industry models SS-1 and X-37-37 glove bags are connected in series, with dessicant in each bag. The first bag serves as an introductory chamber, while the second bag houses the samples and an analytical balance. An air lock between the two bags allows for deposition of the samples into the introductory chamber without contaminating the dry air of the larger bag. The samples can then be weighed and stored in a dry atmosphere. Because this system can be assembled and disassembled with relative ease, it lends itself well to field applications.

SECTION 6

DATA ANALYSIS

AVERAGE RUN PARAMETERS

In order to calculate the resultant values from a test run the average values of the recorded temperatures and pressure drops must be calculated. The pressure drop across the pitot tube, however, requires special attention. The stack velocity is a function of the square root of the pitot ΔP; therefore, a straight average of the ΔP's over a given run would not result in the true average velocity. Because of this, the value used for calculating the average velocity must be the square of the average square root of the velocity heads $\left[(\sqrt{\Delta P})^2 \right]$. This will result in a ΔP value which will allow calculation of the true average velocity.

DRY GAS (SAMPLE) VOLUME

The sample volume measured by the EGR dry gas meter can be corrected to standard conditions (68°F, 29.92 inches Hg) by using the following equation:

$$V_{m_{STD}} = (V_m \gamma) \left(\frac{T_{STD}}{T_m}\right) \left(\frac{P_{BAR} + \frac{\Delta H}{13.6}}{P_{STD}}\right)$$

$$= \left(17.65 \frac{°R}{\text{in. Hg}}\right) (V_m \gamma) \left(\frac{P_{BAR} + \frac{\Delta H}{13.6}}{T_m}\right) \qquad (6\text{-}1)$$

where $V_{m_{STD}}$ = Volume of gas sample through the dry gas meter (standard conditions), cu. ft.
V_m = Volume of gas sample through the dry gas meter (meter conditions), cu. ft.
γ = Gas meter calibration constant.
T_{STD} = Absolute temperature at standard conditions, 528°R
T_m = Average dry gas meter temperature, °R.
P_{BAR} = Barometric pressure, inches of Hg.
ΔH = Average pressure drop across the orifice meter, inches of H_2O.
13.6 = Specific gravity of mercury.
P_{STD} = Absolute pressure at standard conditions, 29.92 inches Hg.

SAMPLE FLOWRATE

The sample flowrate, at standard conditions, can be found using Equation 6-2

$$Q_{s_{STD}} = \frac{V_{m_{STD}}}{\theta} \qquad (6\text{-}2)$$

where $Q_{S_{STD}}$ = Sample flowrate (standard conditions), cu. ft/min.
$V_{m_{STD}}$ = Volume of gas sample through dry gas meter (standard conditions), cu. ft.
Θ = Total sampling time, min.

RECYCLE AND TOTAL GAS FLOWRATES

The recycle and total gas flowrates are monitored by laminar flow elements (LFE's). Therefore, the average flowrates through these respective devices can be determined using the manufacturers calibration charts or an empirically determined calibration equation in the form shown below:

$$Q_{STD} = \left(M\Delta P \left(\frac{\mu_{STD}}{\mu_{LFE}}\right) + B\right)\left(\frac{T_{STD}}{T_m}\right)\left(\frac{P_I}{P_{STD}}\right)$$

$$= 17.65 \left(M\Delta P\left(\frac{\mu_{STD}}{\mu_{LFE}}\right) + B\right)\left(\frac{P_I}{T_m}\right) \qquad (6\text{-}3)$$

where Q_{STD} = Flowrate through laminar flow element (standard conditions), cu. ft/min.
M and B = Empirically determined calibration constants.
ΔP = Average pressure drop across LFE, inches H_2O.
μ_{STD} = viscosity of STD gas (180.1 micropoise).
μ_{LFE} = viscosity of LFE gas, micropoise (see cyclone D_{50} calculations).
T_m = Average temperature at LFE, °R.
T_{STD} = Absolute temperature at standard conditions, 528°R.
P_I = Absolute pressure at inlet to LFE, inches Hg.
P_{STD} = Absolute pressure at standard conditions, 29.92 inches Hg.

VOLUME OF WATER VAPOR

The volume of the water vapor collected from flue gas is calculated as follows:

$$V_{W_{STD}} = V_{\ell_c}\left(\frac{\rho_{H_2O}}{M_{H_2O}}\right)\left(\frac{RT_{STD}}{P_{STD}}\right)$$

$$= 0.04707 \frac{\text{cu. ft.}}{\text{ml}} V_{\ell_c} \qquad (6\text{-}4)$$

where $V_{W_{STD}}$ = Volume of water vapor in the gas sample (standard conditions), cu. ft.
V_{ℓ_c} = Total volume of liquid collected in impingers and/or silica gel, ml.
ρ_{H_2O} = Density of water, 1 g/ml.

M_{H_2O} = Molecular weight of water, 18 lb./lb.-mole.
R = Ideal gas constant, 21.83 inches Hg-cu. ft./lb.-mole-°R.
T_{STD} = Absolute temperature at standard conditions, 528°R.
P_{STD} = Absolute pressure at standard conditions, 29.92 inches Hg.

MOISTURE CONTENT

The moisture content of the stack (or sample) gas is calculated by the equation:

$$B_{wo} = \frac{V_{W_{STD}}}{V_{m_{STD}} + V_{W_{STD}}} \qquad (6\text{-}5)$$

where B_{wo} = Proportion by volume of water vapor in the gas stream, dimensionless.
$V_{W_{STD}}$ = Volume of water in the gas sample (standard conditions), cu. ft.
$V_{M_{STD}}$ = Volume of gas sample through dry gas meter (standard conditions) cu. ft.

The addition of a known amount of dried recycle gas to the measured sample gas upstream of the particle sizing device changes the moisture content of the gas mixture. This new moisture content is determined by the equation below:

$$f_{H_2O} = \left(\frac{Q_S}{Q_S+Q_R}\right) B_{wo} \qquad (6\text{-}6)$$

where f_{H_2O} = Fraction of water vapor (by volume) in the gas mixture, dimensionless.
B_{wo} = Proportion by volume of water vapor in the gas stream, dimensionless.
Q_S = Sample flowrate (wet) at stack conditions, acfm,
Q_R = Recycle flowrate at stack conditions, acfm.

FLOWRATES (ACTUAL CONDITIONS)

In order to calculate the particle cut diameter of the inertial classifier, it is necessary to know the flowrate through the sampler at the actual sampler conditions. This can be accomplished using the following equation:

$$Q_{ACT} = Q_{STD} \left(\frac{1}{1 - f_{H_2O}}\right) \left(\frac{T_s}{T_{STD}}\right) \frac{P_{STD}}{P_s}$$

$$= Q_{STD} \left(\frac{1}{1 - f_{H_2O}}\right) \left(\frac{T_s}{P_s}\right) \left(0.0567 \frac{\text{in. Hg}}{°R}\right) \qquad (6\text{-}7)$$

where Q_{ACT} = Flowrate through sampler (sampler conditions, wet), acfm.
Q_{STD} = Flowrate through sampler (standard conditions), scfm, dry basis.
f_{H_2O} = Fraction (by volume) of water vapor in gas mixture, dimensionless.
T_s = Average temperature of sampler (≈stack), °R.
T_{STD} = Absolute temperature at standard conditions, 528°R.
P_s = Absolute stack pressure, inches Hg.
P_{STD} = Absolute barometric pressure, 29.92 inches Hg.

It is also necessary to calculate the sample and recycle flowrates expressed in terms of stack conditions. The format shown in Equation 6-7 should be used for these calculations. However, for the sample flowrate the moisture fraction becomes the actual stack moisture content and for the recycle flowrate the moisture content equals zero.

RECYCLE RATIO

The actual recycle ratio through the cyclone sampler may be calculated by the equation:

$$PR = \left(\frac{Q_{T_{ACT}} - Q_{S_{ACT}}}{Q_{T_{ACT}}}\right) \times 100\% \qquad (6\text{-}8)$$

where PR = recycle ratio of stack conditions, percent.
$Q_{T_{ACT}}$ = total cyclone flowrate, acfm.
$Q_{S_{ACT}}$ = sample (nozzle) flowrate, acfm.

STACK GAS VELOCITY

The average stack gas velocity or the gas velocity at any one point within the stack can be found using the following equation:

$$V_s = K_p C_p \, (\sqrt{\Delta P}) \left(\frac{T_s}{P_s M_s}\right)^{1/2} \qquad (6\text{-}9)$$

where V_s = Stack gas velocity, ft/sec.
K_p = 85.48 ft/sec $\frac{\text{lb.}}{\text{lb. mole-°R}}$ when these units are used.
C_p = Pitot tube coefficient, dimensionless.
T_s = Absolute stack gas temperature, °R.
ΔP = Square of the average square root of the velocity heads, inches H_2O.
P_s = Absolute stack gas pressure, inches Hg.
M_s = Molecular weight of stack gas (wet basis), lb./lb.-mole,
= $M_d (1 - B_{wo}) + 18 B_{wo}$, Equation 3-2.

B_{wo} = Proportion by volume of water vapor in the gas stream.
M_d = Dry molecular weight of stack gas,
= $32\ f_{O_2} + 44 f_{CO_2} + 28\ (1 - f_{O_2} - f_{CO_2})$, Equation 3-1.
f_A = Volumetric or mole fraction of molecular species A.

CONCENTRATION

The concentration of the particulate matter caught by each stage and the total particulate concentration in the stack gas can be calculated by the equation below:

$$C' = 0.0154 \text{ gr/mg } \left(\frac{M_p}{V_{m_{STD}}}\right) \quad (6\text{-}10)$$

where C' = Concentration of particulate matter for a given stage or in stack gas, grains per standard cubic foot (gr/dscf), dry basis.
M_p = Mass of collected particulate (either per stage or total), mg.
$V_{m_{STD}}$ = Volume of gas sample through dry gas meter (standard conditions) cu. ft.

The units of gr./scf can be converted to milligrams per dry normal cubic meter, mg/dNm^3, by using the following:

$$C = 2293.2\ C' \quad (6\text{-}11)$$

where C = Concentration of particulate, mg/dNm^3.

SAMPLER "D_{50}"

The "D_{50}" or cut-point of each stage of the chosen particle-sizing device should be calculated for accurate determination of the particle size distribution. The cut-point is primarily a function of the actual flowrate through the sampler and the viscosity and density of the gas mixture. The procedure for calculating the actual flowrate (acfm) was described previously. The viscosity of the mixture must be calculated. As was shown in Equation 3-4, it can be determined as follows (Williamson et al., 1983)[6]:

$$\mu = C_1 + C_2 T + C_3 T^2 + C_4 f_{H_2O} + C_5 f_{O_2} \quad (3\text{-}4)$$

where μ is in micropoise, T in °C, and
$C_1 = 160.62$
$C_2 = 0.42952$
$C_3 = 1.0483 \times 10^{-4}$
$C_4 = -74.143$
$C_5 = 53.147$

for T in °R
$C_1 = 51.05$
$C_2 = 0.207$
$C_3 = 3.24 \times 10^{-5}$
$C_4 = -74.143$
$C_5 = 53.147.$

The currently available data concerning calibration of Cyclone I, used to obtain the 10μm cut for PM_{10} measurement, shows the behavior to be described by the equation

$$D_{50} = 0.15625 \left(\frac{M_w P}{T}\right)^{-.2091} Q_{T_{ACT}}^{-.7091} \mu^{.7091} \qquad (6\text{-}12)$$

where D_{50} = Diameter of particles having a 50 percent probability of penetration, microns (μm);
μ = gas viscosity at conditions through cyclone system, micropoise;
$Q_{T_{ACT}}$ = gas flowrate through the cyclone sampler, acfm (sampler conditions, wet)
M_w = molecular weight of mixed gas (see Equation 3-2),
P = absolute stack pressure (in Hg) and
T = cyclone gas (stack) temperature (°R).

Since the proposed PM_{10} Cyclone is actually part of a 5-stage series cyclone system, it may at some point be desirable to operate the full cyclone set with the EGR system. If such is the case, the D_{50}'s for each of the remaining cyclones should be calculated as described in the vendor supplied operator's manual.

PERCENT ISOKINETIC

In order to insure non-biased particulate sampling, the following equation should be used to determine the percentage of isokinetic sampling:

$$I\% = \frac{1.677\ T_s \left[\ 0.00267\ V_{\ell_c} + \frac{V_m \gamma_{cal}}{T_m}\left(P_{BAR} + \frac{\Delta H}{13.6}\right)\right]}{\theta\ V_s\ P_s\ A_n} \qquad (6\text{-}13)$$

where $I\%$ = Percent of isokinetic sampling.
V_{ℓ_c} = Total volume of liquid collected in impingers and/or silica gel, ml.
V_m = Volume of gas sample through dry gas meter (meter conditions), cu. ft.
γ_{cal} = Gas meter calibration constant.
T_m = Absolute average dry gas meter temperature, °R.
P_{BAR} = Barometric pressure at sampling site, inches Hg.
ΔH = Average pressure drop across the orifice, inches H_2O.
T_s = Absolute average stack temperature, °R.
θ = Total sampling time, min.
V_s = Average stack gas velocity, ft/sec.
P_s = Absolute stack gas pressure, inches Hg.
A_n = Cross-sectional area of sampling nozzle, sq. ft.

If $90\% \leq I\% \leq 110\%$, the results are acceptable; otherwise, reject the results and repeat the test.

SAMPLE CALCULATIONS FOR DATA ANALYSIS

In the calculations below, the test data was obtained from the sampling parameters shown on Figure 12. The average values obtained from the runsheet can be seen in Table 3. It should be noted, for the purpose of comparison, the data used here was produced during the January 1985 field demonstration of this prototype sampling system. When comparing the values calculated below with those generated by the computer reduction program (Appendix B) it can be seen the values frequently differed slightly (<±1.0%). This small difference may be attributed to round off error during the manual calculations.

Using Equation 6-1, the total volume of stack gas sampled, at standard conditions, can be determined as shown below:

$$V_{m_{STD}} = (17.65)\ (V_m Y)\ \left(\frac{P_{BAR} + \frac{\Delta H}{13.6}}{T_m}\right) \qquad (6\text{-}1)$$

$$= (17.65)\ (10.007)\ (0.9940)\ \left(\frac{30.02 + \frac{1.14}{13.6}}{516.6}\right)$$

$$= 10.231 \text{ STD cu. ft.}$$

The sample flowrate (at standard conditions) can now be determined using Equation 6-2

$$Q_{s_{STD}} = \frac{V_{m_{STD}}}{\theta}$$

$$= \frac{10.231}{42}$$

$$= 0.2436 \text{ scfm.}$$

Similarly, the flowrates through both the total and recycle laminar flow elements (LFE's) can be found using Equation 6-3:

$$Q_{STD} = 17.65 \left(M\Delta P \left(\frac{\mu_{STD}}{\mu_{LFE}}\right) + B\right) \left(\frac{P_I}{T_m}\right) . \qquad (6\text{-}3)$$

As can be seen, the viscosity of the total gas at the LFE must be calculated. The viscosity of standard gas, as given in Section 6 (see Equation 6-3), is 180.1 micropoise. It should be noted the moisture fraction may be assumed equal to zero since the gas is dried before entering the control console. The viscosity at the LFE can be calculated using Equation 3-4:

$$\mu = 51.05 + 0.207(T) + (3.24 \times 10^{-5})(T^2) - 74.143 f_{H_2O} + 53.147 f_{O_2} \qquad (3\text{-}4)$$

$$\mu_{LFE} = 51.05 + 0.207(520.9) + 3.24 \times 10^{-5}(520.9^2) - 74.143(0) + 53.147(.063)$$

$$= 171.02 \text{ micropoise.}$$

Run Code: CARB_EGR1	Date: JAN. 15, 1986	Stack Temperature: ≈ 310 (°F)	Gas Composition: %CO_2 12.1 %O_2 6.3 %CO NA
Sampler ID: EGR2	Start Time: 0740	Differential Stack Pressure: 0.0 (in.H_2O)	Moisture Content: Estimated @ 16.9% -- corresponds to ≈ 42 ml water collected in condenser
Filter ID: EGR2	End Time: 0822	Ambient Temperature: ≈ 55 (°F)	
Sampler Orientation: HORIZ.	Sampling Duration: 42 (min)	Ambient Pressure: 30.02 (in.Hg)	
Sampling Location: GASSIFIER OUTLET	DGM (initial): 825.525	Gas Velocity: ≈ 40 ft/sec	Pitot Leak Check (Pos) 7.7" H_2O (Neg) 7.5" H_2O
Nozzle Diameter-ID: 0.1853 (in)	DGM (final): 835.532	System Leak Check Before: .004 cfm (+ side); .000 cfm (- side)	Notes: SAMPLED ONLY ONE TRAVERSE POINT TO AVOID INTERFERENCES WITH C.A.R.B. TESTS.
Operator(s): RSMartin	Sample Volume: 10.007 (ft^3)	After: .000 cfm (- side)	
Dual Manometer Leveled and Zeroed? ✓			
Magnehelics Zeroed? ✓			

Run Time	Port No / Trav.Pt.	ΔP Pitot	ΔH Sample	DGM Volume	ΔP Total	P Inlet	ΔP Recycle	T_1 Stack	T_2 Recycle	T_3 Probe	T_4 LFE	T_5 DGM
2	—	.31	1.16	825.525	1.71	5.2	1.52	309	327	335	55	54
5	—	.29	1.15	—	1.65	5.5	1.75	309	330	330	56	53
10	—	.30	1.18	—	1.72	5.4	1.75	310	333	330	58	58
15	—	.295	1.10	—	1.65	5.4	1.75	310	335	345	60	56
20	—	.295	1.15	—	1.70	5.3	1.75	311	311	320	62	58
30	—	.30	1.12	—	1.70	5.0	1.80	311	314	322	67	58
35	—	.30	1.15	—	1.70	4.8	1.80	311	314	321	68	58
42	OFF			835.532								
AVG.		0.299	1.144		1.690	5.229	1.731	310.1	323.4	329.0	60.9	56.6

Figure 12. Completed EGR Runsheet.

Table 3. Sample Run Parameters

Temperatures (averaged)

Stack:	310.1°F
Recycle (@ Stack):	323.4°F
LFE:	60.9°F
Dry Gas Meter:	56.6°F

System Pressures (averaged)

ΔH_{ORI}:	1.14 inches H_2O
ΔP_T:	1.69 inches H_2O
P_{Inlet}:	5.23 inches H_2O
ΔP_R:	1.69 inches H_2O
ΔP_{PTO}:	0.30 inches H_2O

Miscellanea

P_{BAR}:	30.02 inches Hg.
ΔP_{Stk}:	0.0 inches H_2O
V_{DGM}:	10.007 cu. ft.
Run Time:	42.0 min.

$\%CO_2$:	12.1
$\%O_2$:	6.3
Water Collected:	44.2 ml
Nozzle Dia.:	0.1853 inches

Collected Masses

Cyc I:	12.5 mg
Filter:	237.4 mg
Imp. Res.:	0.0 mg

Blank Values

Cyc. Rinse:	0.0 mg
Filter Rinse:	0.0 mg
Filter Blank:	0.0 mg
Imp. Rinse:	0.0 mg

Calibration Values

C_p(Pitot):	0.83
$\Delta H@$ (Orifice):	10.980
M_T (Total LFE):	0.2298
B_T (Total LFE):	-0.0058
M_R (Recycle LFE):	0.0948
B_R (Recycle LFE):	-0.0007
γ (Dry Gas Meter):	0.9940

For the total LFE flowrate, from the given data

$$Q_{T_{STD}} = 17.65 \left[(0.2298)(1.69)\left(\frac{180.1}{171.02}\right) + (-0.0058) \right] \left(\frac{30.02 + \frac{5.23}{13.6}}{520.9}\right)$$

$$= 0.4154 \text{ scfm. (dry basis).}$$

For the recycle LFE

$$Q_{R_{STD}} = 17.65 \left[(0.0948)(1.69)\left(\frac{180.1}{171.02}\right) + (-0.0007) \right] \left(\frac{30.02 + \frac{5.23 - 1.69}{13.6}}{520.9}\right)$$

$$= 0.1724 \text{ scfm.}$$

The volume of water collected from the stack gas is calculated as is shown by Equation 6-4:

$$V_{W_{STD}} = 0.04707 \ (V_{\ell_C}) \qquad (6\text{-}4)$$

$$= 0.04707 \ (44.2)$$

$$= 2.080 \text{ STD cu. ft.}$$

The moisture content of the stack, defined in Equation 6-5, is calculated as shown:

$$B_{wo} = \frac{V_{W_{STD}}}{V_{M_{STD}} + V_{W_{STD}}} \qquad (6\text{-}5)$$

$$= \frac{2.080}{10.231 + 2.080}$$

$$= 0.169 \text{ or } 16.9\%.$$

The moisture fraction, f_{H_2O}, of the gas entering the particle sizing device is decreased from the stack gas moisture as a function of the recycle ratio. For the given data f_{H_2O} may be determined as shown in Equation 6-6

$$f_{H_2O} = \left(\frac{Q_S}{Q_S + Q_R}\right) B_{wo}. \qquad (6\text{-}6)$$

As can be seen, however, the sample and recycle gas flowrates at actual, stack conditions must first be determined using the relationship

$$Q_{ACT} = 0.0567 \ Q_{STD} \left(\frac{T_S}{P_S}\right) \left(\frac{1}{1 - f_{H_2O}}\right). \qquad (6\text{-}7)$$

For the sample flowrate, f_{H_2O} becomes B_{wo}, therefore

$$Q_{S_{ACT}} = 0.0567\ (0.2436)\ \left(\frac{460+310.1}{30.02+\frac{0.0}{13.6}}\right)\ \left(\frac{1}{1-0.169}\right)$$

$$= 0.4264 \text{ acfm.}$$

Since the recycle gas contains no moisture, f_{H_2O} becomes zero and the recycle flowrate, at stack conditions, may be found as follows:

$$Q_{R_{ACT}} = 0.0567\ (0.1724)\ \left(\frac{770.1}{30.02+\frac{0.0}{13.6}}\right)\ \left(\frac{1}{1-0.0}\right)$$

$$= 0.2508 \text{ acfm.}$$

The water fraction of the mixed cyclone gas, f_{H_2O}, may now be determined

$$f_{H_2O} = \left(\frac{0.4264}{0.4264 + 0.2508}\right)\ (0.169)$$

$$= 0.1064 \text{ or } 10.64\%.$$

In turn, the actual (stack conditions) flowrate through the fractionating cyclone may be found

$$Q_{T_{ACT}} = 0.0567\ (0.4154)\ \left(\frac{770.1}{30.02+\frac{0.0}{13.6}}\right)\ \left(\frac{1}{1-0.1064}\right)$$

$$= 0.6761 \text{ acfm.}$$

The actual percent recycle may be calculated using Equation 6-8, as is shown below:

$$PR = \left(\frac{Q_{T_{ACT}} - Q_{S_{ACT}}}{Q_{T_{ACT}}}\right) \times 100\% \qquad (6\text{-}8)$$

$$= \left(\frac{0.6761-0.4264}{0.6761}\right) \times 100\%$$

$$= 36.9\%.$$

As detailed under EPA Reference Method 2 and Equation 6-9 of this manual, the average stack velocity, $\overline{V}_s$, is determined as follows:

$$\overline{V}_s = 85.48\ C_p \sqrt{\Delta P}\ \left(\frac{T_s}{P_s M_s}\right)^{0.5} \qquad (6\text{-}9)$$

As can be seen, the wet molecular weight of the stack gas must be determined before the average stack gas velocity can be found. Using Equations 3-1 and 3-2

$$M_d = 32f_{O_2} + 44f_{CO_2} + 28\ (1-f_{O_2}-f_{CO_2}) \qquad (3\text{-}1)$$

$$= 32(.063) + 44(.121) + 28(1-.063-.121)$$

$$= 30.188$$

and

$$M_w = M_s = M_d\ (1-B_{wo}) + 18B_{wo}$$

$$= 30.188\ (1-.169) + 18\ (.169)$$

$$= 28.128.$$

Hence, the average stack velocity (Equation 6-9) may be determined on

$$\overline{V}_s = 85.48\ (0.83)\ \sqrt{0.30}\ \left(\frac{770.1}{(30.02+\frac{0}{13.6})\,28.128}\right)^{0.5}$$

$$= 37.11 \text{ ft/sec.}$$

The particulate loadings can be grouped into three concentrations of interests: particulate matter greater than the size cut (i.e. > 10μm), less than the size cut (the PM_{10} fraction), and the total particulate loading. Equations 6-10 and 6-11 show the concentration relationships for the given units

$$C' = 0.0154\ \left(\frac{M_p}{V_{M_{STD}}}\right) \text{ grains/dscf} \qquad (6\text{-}10)$$

and

$$C = 2293.2\ C' \text{ mg/dNm}^3\ . \qquad (6\text{-}11)$$

It should be noted the mass (M_p) represents the raw mass of the particulate matter recovered corrected by subtraction of any "blank" values.

Using the given data, for particulate matter > 10μm

$$C' = 0.0154\ \left(\frac{12.5}{10.231}\right)$$

$$= 0.01882 \text{ gr/dscf}$$

and

$$C = 2293.2\ (0.01882)$$

$$= 43.16 \text{ mg/dNm}^3.$$

For PM_{10} (less than 10μm) particulate matter

$$C' = 0.0154 \left(\frac{237.4}{10.231}\right)$$

$$= 0.3573 \text{ gr/dscf}$$

and

$$C = 2293.2 \ (0.3573)$$

$$= 819.4 \text{ mg/dNm}^3.$$

The total particulate loading can be found as shown below:

$$C' = 0.0154 \left(\frac{249.9}{10.231}\right)$$

$$= 0.3762 \text{ gr/dscf}$$

and

$$C = 2293.2 \ (0.3762)$$

$$= 862.7 \text{ mg/dNm}^3.$$

To verify that the size cut actually obtained was within tolerance (±10%) of the target size cut, 10μm, the D_{50} of the cyclone must be calculated from the actual run data.

The viscosity of the combined gas through the cyclone (using f_{H_2O} for B_{wo}) must be determined before the specific size cut achieved may be found. Using Equation 3-4:

$$\mu = 51.05 + 0.207(T) + (3.24\text{x}10^{-5})(T^2) - 74.143 \ f_{H_2O} + 53.147 \ f_{O^2}$$

$$= 51.05 + 0.207(770.1) + (3.24\text{x}10^{-5})(770.1^2) - 74.143(0.1064) + 53.147(.063)$$

$$= 225.14 \text{ micropoise.}$$

Further, the wet molecular weight of the mixed (cyclone) gas must also be determined. Using Equation 3-2 and substituting f_{H_2O} for B_{wo}

$$M_w = 30.188(1-0.1064) + 18(0.1064)$$

$$= 28.891.$$

The "cut" of the cyclone may now be determined using Equation 6-12:

$$D_{50} = 0.15625 \left(\frac{M_w P}{T}\right)^{-.2091} \ Q_{T_{ACT}}{}^{-.7091} \ \mu^{.7091} \qquad (6\text{-}12)$$

$$= 0.15625 \left(\frac{28.891(30.02+\frac{0}{13.6})}{770.1}\right)^{-.2091} (0.6761)^{-.7091} (225.14)^{.7901}$$

$$= 9.37\ \mu m.$$

Finally, the isokinetic sampling ratio may be found as shown by Equation 6-13:

$$I\% = \frac{1.677\ T_s \left[0.00267\ V_{l_c} + \frac{V_m \gamma\ cal}{T_m} \left(P_{BAR} + \frac{\Delta H}{13.6}\right)\right]}{\theta V_s P_s A_n} \qquad (6\text{-}13)$$

$$= \frac{1.677(770.1)\left[0.00267(44.2) + \frac{(10.007)(0.994)}{516.6}\left(30.02 + \frac{1.14}{13.6}\right)\right]}{(42)(37.11)\left(30.02 + \frac{0}{13.6}\right)(1.873 \times 10^{-4})}$$

$$= 102.8\%.$$

SECTION 7

MAINTENANCE AND CALIBRATION

It is recommended a notebook or other record of all maintenance and calibration data be kept. This will proivide a definite and current record of all information pertinent to reliable operation the EGR sampling system.

VACUUM SYSTEM

Insert a plugged 1/2" male quick connect into the sample inlet of the EGR control console. Turn the pump switch to ON. Turn the Coarse-Adjust valve to the ON position and close fully the Fine-Adjust valve. The exhaust gas recirculation (EGR) valves should also be fully closed. The vacuum gauge should read about 25 inches of mercury when ambient barometric pressure is near 30 inches of mercury. If this pressure cannot be achieved, a leak or sticking pump vane should be suspected. If the leakage rate measured by the dry gas meter exceeds 0.02 cubic feet per minute, find and correct the leak or leaks. Parts to check are the pump, vacuum gauge, metering valves, and tubing.

PUMP MAINTENANCE

Because the gas recirculated within the EGR system must be free of any foreign particles or vapors, the system is equipped with a leak-free, carbon-vane pump. The pump requires no lubrication and little maintenance is needed to insure long working life. The most important factor in assuring long pump life is to allow only clean, dry gas to circulate through the pump. This is accomplished through the sampling systems backup filter and impingers or condensers. Unlike the oil-lubricated pumps used in most commercial Method 5 control boxes, this pump should never be operated with oil in the muffler jars.

During start up if the motor fails to start or hums, pull the plug and check for the correct current. It should be 5 to 6 amperes. Also visually inspect the plug and switch. If the unit is extremely cold, it may be helpful to bring the unit to room temperature before starting.

Most pump trouble can be corrected by flushing the unit according to the manufacturer's instructions rather than disassembly. A noisy or inefficient pump is frequently caused by nothing more serious than a vane stuck in a rotor slot due to foreign material in the unit. Separate the pump from the system and add several teaspoons of solvent slowly at the intake while the unit is running. Lay the unit on its side with the outlet downward so the solvent will work out again. Recommended commercial solvents include Loctite Safety Solvent, Inhibisol Safety Solvent, or Dow Chemical Chlorothane.

If flushing does not eliminate the problem, remove only the end-plate and the four carbon vanes. Remove any visible foreign materials and clean the chamber with solvent. Normal wear of the carbon vanes may cause buildup on inner pump walls; this buildup should also be cleaned with the solvent. Any broken or excessively worn vanes should be replaced. Replace the pump end-

plate and check the unit for leaks. This is accomplished by plugging the inlet of the pump and connecting a gas meter to the outlet. If the pump causes the gas meter to register a reading, the pump end plate should be retightened and leak-checked again. This should be repeated until the unit is leak-free.

CALIBRATION OF FLOW METERING DEVICES

The four flow metering devices of the EGR sampling system should be calibrated prior to each field test or at least spot checked using a three-point check. The devices should be calibrated with an NBS traceable standard, such as a wet test meter, laminar flow element, or a positive displacement meter. The outlet of the calibration standard is connected to the sample inlet of the EGR control console and the EGR pump is used as the flow source. To calibrate the sample dry gas meter and orifice completely close valves number three and four, and open valve five. The dry gas meter can then be calibrated as in EPA Reference Method 5. The sample orifice and total flow laminar flow element (LFE) can be calibrated simultaneously. The orifice calibration equation is expressed in the form

$$Q = \frac{.9615}{\sqrt{\Delta H@}} \left(\frac{\Delta H T}{P_m M}\right)^{0.5} \qquad (3\text{-}17)$$

where Q = measured flowrate (acfm),
ΔH = pressure differential across device (inches H_2O),
T = temperature of gas at meter (°K),
P_m = absolute pressure at meter inlet (inches Hg),
M = molecular weight (≈ 28.97 for std air), and
$\Delta H@$ = calibration constant.

The total and recycle LFE's behave in much more linear fashion and can best be described by the equation

$$Q = M\Delta P \left(\frac{\mu_{STD}}{\mu_{LFE}}\right) + B \qquad (3\text{-}19)$$

where μ_{STD} = viscosity of standard air (180.1 micropoise),
μ_{LFE} = viscosity of sample gas (micropoise), and
M,B = linear calibration constants.

By closing valve V_5 and opening valves V_3 and V_4, the recycle LFE may be calibrated. It should also be noted that the total flow LFE may be calibrated in this flow pattern as well. For the sake of simplicity and future comparisons, it is suggested both LFE's be calibrated simultaneously.

MAGNEHELIC DIFFERENTIAL PRESSURE GAUGES

Magnehelic differential pressure gauges are precision instruments assembled and precalibrated by the manufacturer. If trained instrument mechanics are not available, it is recommended that any instruments requiring repair be returned to the factory.

No lubrication or periodic servicing is required. If the interior is protected from dust, dirt, corrosive gases and fluids, years of trouble free service may be expected.

Zero Adjust

Set the indicating pointer exactly on the zero mark, using the external zero adjust screw on the cover at the bottom. Note that the zero check or adjustment can only be made with the high and low pressure taps both open to atmosphere.

Calibration Check

For service requiring a high degree of continued accuracy, periodic calibration checks are recommended, using the following procedure. In general, the magnehelic calibration should be checked along with the LFE's.

1. As a comparison gauge, use a hook gauge, micromanometer or inclined gauge of known accuracy.

2. Connect the Magnehelic gauge and test gauge together with two leads from a "T". Connect rubber tubing to the third leg of the "T" and impose the pressure, slowly.

3. Be certain no leaks exist in the system and provide adequate time for comparison gauges to reach equilibrium, since fluid drainage and different dynamic characteristics can affect the reading.

Recalibration

1. Remove plastic cover.

2. Remove two screws holding scale and slide scale out, using care not to damage pointer.

3. Loosen two set screws in range spring clamp, Dwyer Part No. NUA-70B and move toward the helix to increase the range and back to decrease. Secure the clamp with the set screws, replace scale, check zero and compare reading as in preceding paragraph.

4. Replace cover. Note that cover must be tight and leakproof for accurate readings on high pressure side. Observe following procedure.

    a. Place cover in position with notch engaged and with "O"-ring properly seated.
    b. Jockey zero adjust screw into position so its hex end is inserted in the socket set screw which actuates the zero adjusting mechanism.
    c. Hold cover in position and screw bezel down snug. Note that "O"-ring must take some squeeze in order to effect an air tight seal. Caution: If bezel binds due to galling action of aluminum surfaces lubricate sparingly with light oil or molybdenum sulphate compound.

d. Trouble shooting.
   1. Gauge sluggish.
      - Leads may be plugged or leaking.
      - Cover may be loose or leaking.
      - Pointer may be touching scale.
      - Jewels supporting helix over tightened.
   2. Gauge fails to indicate zero properly.
      - See comments above regarding sluggish readings.
      - Iron particles in strong magnetic field between helix and magnet. If found, they may be removed by touching each particle and withdrawing it with a small screw driver.
      - Magnet shifted and touching helix.
   3. Apparent inaccuracy.
      - See preceding comments.
      - Improper connections to pick up desired differential.
   4. Consult factory for unusual conditions of temperature, pressure, etc., and the effect on gauge operation and accuracy.

DUAL MANOMETER

Visually check the pitot and orifice manometer lines. They should be free of fluid. Check for leaks, especially around the fluid-level zeroing controls and drain screws. Wipe the dual manometer clean. The back can be cleaned with compressed air or the device can be removed from the control panel and wiped clean. If the dual manometer is unusually dirty, clean as recommended on the instruction plate.

After making sure that the manometer ports are open (1 1/2 turns counter-clockwise from the seat) and the manometer lines are connected, level the manometer and check the fluid level. The manometer can be filled with fluid by removing the screw on the left side. When the manometer is zeroed (the oil meniscus and the reflected image at zero are aligned) the fluid-level plunger (zeroing control) should have about 1/4 to 1/2 inch travel inward. Note: During rough shipment, the manometer lines should be disconnected and the manometer ports closed by turning clockwise until sealed. If for any reason the manometer unit has been inverted, be sure the floating check valves of the manometer have returned to their normal position. These floating valves are located under the manometer ports and must be in the normal position to use the manometer.

PITOT TUBE

The pitot tube should occasionally be inspected for any deformation of the pressure inlets, as this may change the pitot calibration coefficient. Any dents or nicks should be repaired or the pitot head should be replaced if the damage warrants it. Before each test run, blow gently into each pitot inlet to check for obstructions. If the pitot tubes are clear, the pitot tube gauge will respond. If no response is noted, blow out pitot lines with compressed air. The pitot can be checked for leaks by plugging one end of the tube and applying a positive pressure at the opposite end. If the tube will not maintain pressure, a soap solution can be used to identify the location of any leaks.

Pitot Tube Calibration

To calibrate the EGR pitot tube, measure the velocity pressure, ΔP, at the same point within a cross-section of a straight run of ductwork with a standard pitot tube and the S-type EGR pitot tube for a desired range of gas velocities. The EGR pitot should be calibrated twice, as is normally recommended in EPA Reference Method 2, reversing the direction of the legs during the second calibration. For each velocity, determine a pitot tube coefficient as:

$$C_p = 0.99 \left(\frac{\Delta P_{STANDARD}}{\Delta P_{EGR}}\right)^{1/2} \quad (7\text{-}1)$$

where C_p = EGR S-Type calibration coefficient, dimensionless;
0.99 = C_p value for standard pitot tube, dimensionless;
$\Delta P_{STANDARD}$ = velocity pressure drop of standard pitot tube, inches of water; and
ΔP_{EGR} = velocity pressure drop of EGR S-Type pitot tube, inches of water.

The average value of C_p for each direction over the range of velocities used should be calculated. With normal S-Type pitot tubes the average calibration coefficient, C_p, equals 0.85 ± 0.03 in both directions. However, due to the design of the EGR pitot tube, the coefficient may vary from the previously mentioned limits. This presents no problem if the standard deviation of the calibration coefficient is within the tolerance outlined in EPA Reference Method 2.

NOZZLES

Visual inspection of the EGR nozzle should be done prior to any testing. If necessary, repair the nozzle with a plumb bob (for inside damage) or emery paper (for outside damage). It should be noted that after any nozzle repair, the nozzle diameter should be remeasured. The knife edge of the nozzle should be covered with serum caps or similar covers to avoid damage when not is use.

EGR Nozzle Measurement

Using a micrometer, measure the inside diameter of the EGR nozzle to the nearest 0.001 inch. Make three separate measurements using different diameters each time and obtain the average of the measurements. The largest deviation from the average should not exceed 0.004 inches. If the variation is more than 0.004 inches, repair the nozzle as noted above. Note the correct diameter in the EGR Calibration Notebook and on the field data sheet(s).

THERMOCOUPLE CALIBRATION AND MAINTENANCE

The thermocouples used to measure the various temperatures within the EGR sampling train (Chromel-Alumel; Type K) should be checked for proper calibration before installation in the system. It is recommended a two-point calibration check using an ice bath and a boiling water bath. If any individual thermocouple does not produce a reading within three degrees of the expected value, it should be replaced with another thermocouple of the same type. If all thermocouples show a bias, the readout should be adjusted or recalibrated according to the manufacturer's procedure.

The thermocouples throughout the EGR system should occasionally be checked against room temperature using a mercury-in-glass thermometer as the standard. If any thermocouples do not read within ±5°C, the thermocouples or readout should be replaced or recalibrated.

EGR SAMPLING PROBE MAINTENANCE

Probe Cleaning

Before each field test all lines of the EGR heated sampling probe should be cleaned. This includes the sample, recycle, and pitot tube lines. Clean the probe internally by brushing, first using tap water, then distilled, deionized water, followed by acetone or dichloromethane. Rinse the internal tubes with the chosen orgainc solvent and allow it to air dry. Visually inspect the probe for cleanliness and repeat the procedure if necessary. The recycle line should be rinsed even if it appears clean. The pitot lines probably will only require water rinse and blowing out with compressed air.

The tube fittings associated with the EGR probe sample lines should also be cleaned by brushing, rinsing with distilled, deionized water, followed by acetone or dichloromethane; then allow to air dry. As with the nozzle, all open ends of the probe should be covered with serum caps or saran wrap when not in use to prevent contamination.

Probe Heater

To check the probe heater, plug the probe heater line and controlling thermocouple into the control case, and turn the heater controller on to approximately 300°F. The indicator light on the controller should come on and the probe should become warm to the touch in a few minutes. After a few minutes, the indicator light should begin to cycle on and off. If the probe does not heat, check the probe for loose connections. If the probe still does not heat, it may be necessary to remove the probe liner from the probe sheath for inspection of the heating element. Remove the three set screws and tube fittings at the outlet side of the probe. The front end connector can then be unscrewed and the probe lines gently slid out. After the probe lines have been removed, the insulation may be unwrapped and the probe heating element can be visibly inspected for shorts or burned spots. An ohmmeter can also be used to measure the resistance between leads (approximately 17 ohms) and also to ground (infinite). Deviations from these values indicate faulty wiring.

After any electrical problem has been solved, the probe lines should be rewrapped with insulating material, and the probe should be reassembled.

CONDENSING SYSTEM

Since it is generally preferable to operate the EGR system with a Method 17 rather than Method 5 filter configuration, a condenser and silica gel column may replace the built-in impinger train assembly. An impinger system will be required if the "backhalf" catch is to be measured. Whichever system is used for collection of water vapor from the sampled stack gas, it must be clean and free of leaks before being used. Glass impingers should be cleaned with distilled, deionized water, and then acetone; air dry. Stainless steel condensers should also be rinsed using the same procedure and allowed to air dry, inverted to insure total drainage. The drying can be speeded by blowing out the condenser with compressed air. Silica gel columns (along with condensers) should be leak tested along with the control box or separately by applying positive pressure at the inlet and plugging the outlet. Ideally, these devices should maintain a pressure of at least 10 inches of mercury above absolute. It is recommended new silica gel be used for each field test.

SECTION 8

INTERNAL QUALITY CONTROL CHECKS

Field use of the Emission Gas Recycle (EGR) Sampling System is a difficult task. The accuracy required is more nearly that for a laboratory program than for a conventional source test. There are many places in the operational sequence where errors can occur in spite of a conscientious effort to do a good job. A quality assurance program attempts to discover inaccuracies before they are propagated throughout the test program. A conscientious operator will be aware of the problems unique to each sampler and to the total EGR sampling system itself and will take steps to avoid them.

Problems associated with the particle classifier, such as particle bounce and reentrainment, and effective sample recovery techniques should be addressed in the operator's manual. Other quality assurance checks, such as system leaks, flow checks, meter calibrations, weighing techniques, etc. should be carefully monitored by the EGR operator.

SYSTEM LEAKS

Conscientious leak testing will preclude any sampling errors due to leaks. However, if a leak occurs during testing it may be noticed by a sudden change in the pressure readings of the system. If a leak goes unnoticed during testing, it will adversely affect the final test results. Leak checks made at the operating temperature will identify leaks not found at ambient conditions. Besides loosened fittings, internal sampler leaks may be caused by nicked or warped metal or hardened rubber "O"-rings. It is recommended that a quick leak check be performed after warmup.

FLOW CHECKS

By definition the total flow through the EGR sampling system is the sum of the recycle and sample gas flow. Since the EGR system uses differential pressure moitoring devices (manometers and magnehelics) to monitor the above three flowrates, any deviation from the expected value can be immediately noticed. For example, if the total flow magnehelic reading relates to 1.0 cfm and the sample flow manometer relates to 0.6 cfm, the reading on the recycle magnehelic must relate to 0.4 cfm. During operation the total flowrate through the system is held constant; therefore, if the sample flowrate changes to remain isokinetic, the recycle flowrate must change by an equal, but opposite amount.

If the flows are fairly constant, the EGR dry gas meter may also be used as a quality assurance check. By measuring the time per revolution of the gas meter rotation needle, the sample flowrate can be determined. This, by definition, should equal the difference of the total and recycle gas flowrates.

CALIBRATION

Calibration of the chosen particle-sizing device should be performed according to procedures outlined in the particular operator's manual specific to each sampler. The calibration of the metering devices, nozzles, pitots, etc. to be used in conjunction with the EGR sampling system should be performed at approximate run conditions. In order to assure the validity of the field test, a spot calibration of the EGR equipment is recommended upon completion of the field test. This would help eliminate possible errors in final data analysis.

WEIGHING TECHNIQUES

The manufacturer's directions should be followed when operating the balance. The balance should be calibrated at least once a day. Several times throughout the day the repeatability of measurements should be checked by weighing a sample and a control weight. A control or test weight is a small piece of material (ceramic or metallic) whose weight does not change with changes in temperature or humidity or through repeated handling. Small pieces of stainless-steel or platinum are proven control weights. Dry weight checks are made by desiccating the samples, weighing, then desiccating again and reweighing. When the agreement is within the repeatability of the balance, dry weight has been achieved.

DATA REVIEW

After the data have been collected, they should be examined for any inconsistencies or weak points. Careful decisions should be made concerning "outliers"--data points which are not compatible with the bulk of the data.

SECTION 9

CALIBRATION DATA FOR SoRI/EPA CYCLONE I

EGR nozzles have been designed for Cyclone I of the SoRI/EPA Five Stage Series Cyclones (Smith, et al., 1979)[9] and the commercial version of it (Andersen Samplers, Inc., Atlanta, GA). The calibration data available for Cyclone I originates from the work of Smith, et al. (1979) and Farthing, et al (1985),[10] and recent work concerned directly with PM_{10}. All of these calibrations were performed with monodisperse dye aerosols produced using a vibrating orifice aerosol generator (VOAG).

In each series of calibrations, the cyclone was backed up by an absolute filter which collected the test particles that were not removed by the cyclone. After each run, solvent washes of the internal surfaces of the cyclone, connecting tubing, and filter were then made using measured amounts of solvent. The quantities of the particulate matter collected by the various surfaces were then determined by photometric analysis of the dye concentrations in the washes. From these data the deposition pattern in the cyclone could be determined together with the total particulate mass which entered it and the fraction of the mass which it collected.

In the original data reported by Smith et al.,[9] the aerosol stream flowed into the cyclone through a tube which had the same diameter as the cyclone inlet (0.5 inch). During these calibrations two types of experiments were performed. In the first type, the cyclone flowrate was held constant and the particle size was varied from one run to the next so as to define the shape of the collection efficiency curve of the cyclone. The collection efficiency curve as measured in these experiments can be described by a log-normal function with a Sigma-g of about 1.18. In the second type of experiment, the flowrate required to obtain a 50% collection efficiency was found for a number of particle diameters and operating temperatures. These latter data permitted the generation of equations for predicting the cyclone D_{50} for different operating conditions. Smith et al. used the sample flowrate and gas viscosity to characterize the behavior of the cyclone in terms of its D_{50} at different operating conditions. Farthing et al. (1985)[10] reported the results of calibrations of Cyclone I which were carried out in a manner similar to that used by Smith et al and these are also included in Figure 13. Subsequent to the work reported by Smith et al. the Reynolds number of the flow in cyclone outlets was found to be the governing factor in their performance through the particle Stokes number for 50% collection efficiency (Beeckmans, 1979).[11] Figure 13 presents the data obtained by Smith et al. and Farthing et al. in terms of the Stokes number for 50% collection and the Reynolds number of the flow in the cyclone inlet tube. (The Reynolds number in the outlet tube is approximately equal to that in in the inlet, but difficult to define because of the reversed exit.) A more detailed discussion of cyclone behavior as related to particle Stokes number and cyclone Reynolds number has been given by McCain et al (1986).[12]

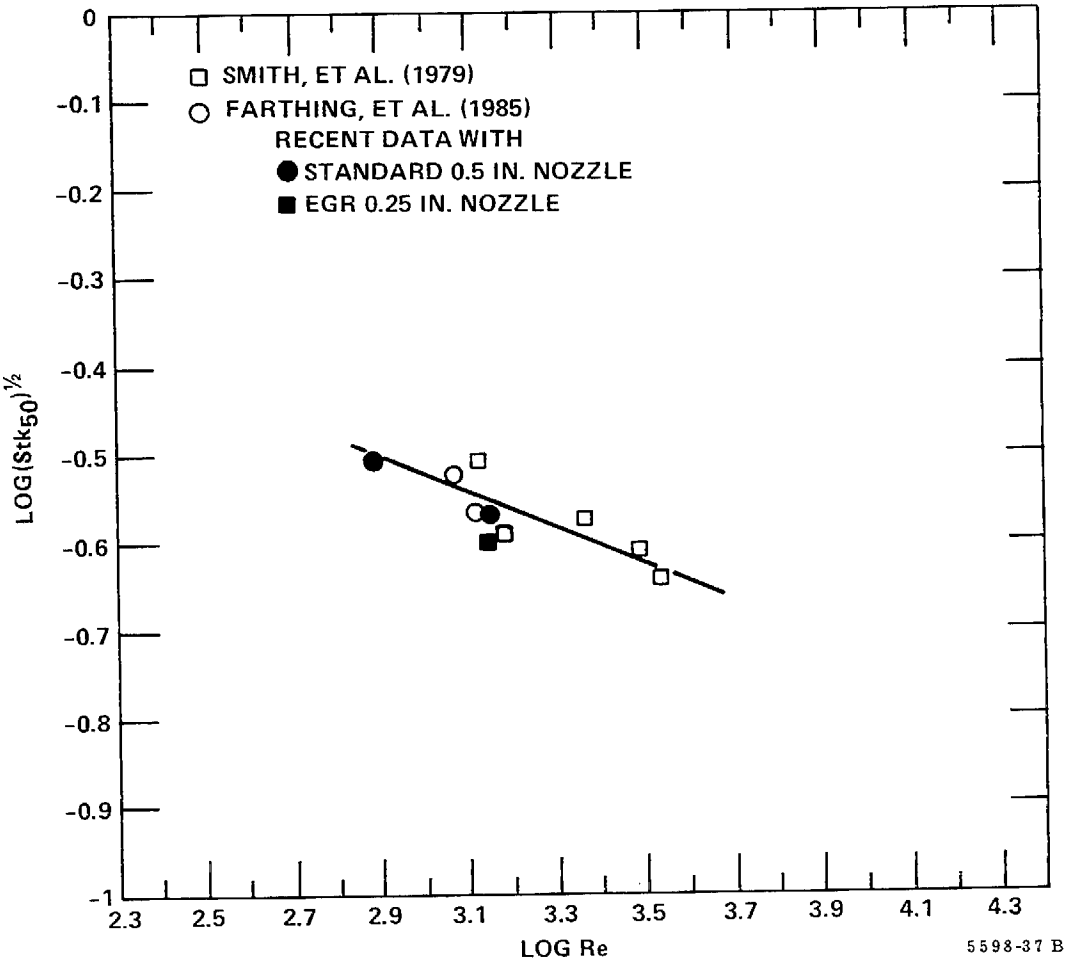

Figure 13. Calibration data for Cyclone I of the five-stage cyclone sampler. Data from Smith and Wilson (1979), Farthing, et al. (1985) and unpublished data from this contract. (Air only, variable temperature and flow rate).

These calibration results are used to determine the appropriate flowrate for PM_{10} sampling by first generating an equation relating the particle Stokes number for 50% collection efficiency, Stk_{50}, and Re are given by the expressions:

$$\sqrt{Stk_{50}} = D_{50}\sqrt{2Q/\rho\pi\mu d^3}, \qquad (9\text{-}1)$$

and

$$Re = 4\rho Q/\pi\mu d \qquad (9\text{-}2)$$

where

Q = cyclone flowrate in actual cm^3/sec,
μ = gas viscosity in poise,
d = cyclone inlet diameter (1.27cm),
ρ = gas density in gm/cm^3.

The solid line in Figure 13 is the empirical function:

$$\sqrt{Stk_{50}} = 1.285\ Re^{-0.2091} \qquad (9\text{-}3)$$

obtained by a least squares fit to the data. It is used for PM_{10} sampling by setting D_{50}=10μm and solving for Q in terms of the gas conditions of the source being tested. This equation is used in a different form in Section 3 in describing the setup calculations for sampling.

The aerosol entry into Cyclone I in the experiments described above was not realistic in terms of field operation. In actual applications, the sample stream is withdrawn isokinetically through a nozzle whose tip size is substantially smaller in diameter than the cyclone inlet. The sample stream must then expand in a rather short distance to the inlet diameter and the question of whether it can do so or what the effect on the cyclone cut diameter might be if it does not is problematical. The modification of the nozzle that is required for operation in the EGR mode poses additional questions regarding the performance of the cyclone for PM_{10} applications. Therefore, a new series of experiments were begun to resolve these questions. In this recent set of calibrations, the aerosol was introduced to the sampler in a manner which more realistically simulated isokinetic sampling in the field. For the larger nozzles, which are used for low velocities, the aerosol flowed through a 3" pipe and for the smaller nozzles the aerosol flowed through a 1.5" pipe. For each experiment the nozzle mounted on Cyclone I was located at the center of the pipe exit. The gas flowrate through the pipe was adjusted so that measured gas velocity matched the nozzle velocity. The results of these experiments to date were also included in Figure 13.

Figure 14 presents the results of these calibrations as aerodynamic D_{50} versus Cyclone I flowrate. The close agreement between the EGR 0.25" nozzle and the 0.5" standard inlets with one another and with the older data suggests that the EGR nozzle has little if any effect upon behavior of the cyclone. There is substantial scatter in the data, ±10%, and the range of conditions (Reynold's number) tested is limited. The assumed functional dependence may not be appropriate for values of the inlet Reynolds number outside the range of

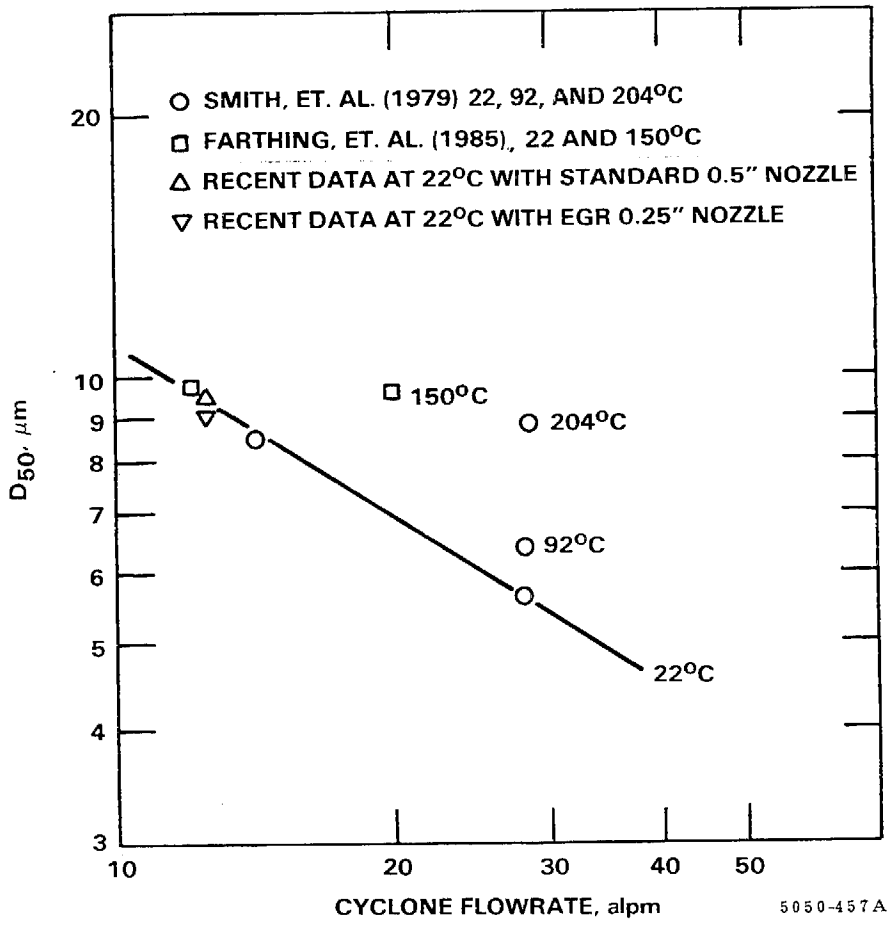

Figure 14. Cyclone I Aerodynamic D_{50} versus flowrate at various temperatures.

the calibrations. Substantially more data at more conditions, other nozzle sizes and varying EGR recycle rates, are needed to verify the influence of the nozzle geometry and cover a wider range of Reynolds number to provide for all expected field operation.

SECTION 10

FIELD EVALUATION OF THE EGR CONCEPT

Following development of the EGR prototype sampling system, field evaluations were performed under USEPA contracts (Williamson, et al., 1985). The Emission Gas Recycle System was used to measure total mass and particulate size fractions at three separate coal-fired power plants. The test series compared results from the EGR system with those from standard Method 17 mass train systems, conventional cyclone and impactor trains, and similar trains using another PM_{10} candidate method (SIM5).[8] During the first two tests, the EGR and conventional cyclone train consisted of Cyclones I and IV of the SoRI/EPA series cyclone train, followed by a 47mm glass fiber filter. For the final test of the series, a full SoRI five-stage series cyclone system was used for both systems. University of Washington Mark V impactors were also used for comparisons in all testing.

TEST NO. 1

The first field test took place at one of the twin 56 MW coal-fired boilers at a utility generating station. The plant nominally operates at minimum (half) load; however, boiler conditions occasionally changed as dictated by demand. The sampling location chosen was the ducting between an outdated, somewhat inefficient electrostatic precipitator and a retro-fitted, more efficient ESP.

The overall test was divided into two subtests. Subtest A involved the comparison of traverses performed with the EGR train and a standard Method 17 (M17) mass train. To eliminate spatial bias, a probe was configured with a cyclone set (SoRI Cyclone I, Cyclone IV and a 47mm filter) using an EGR nozzle and a collocated 47mm filter. The large diameter of this system required plant installation of six-inch ports. Three traverse points were selected which represented the maximum point-to-point velocity change accessible through the six-inch ports. The recycle rate was then adjusted to achieve isokinetic sampling at each point while maintaining the chosen the chosen constant flowrate through the cyclone set. The flowrate through the collocated 47 mm filter was adjusted at each point according to isokinetic sampling protocol.

In Subtest B, the EGR-M17 hardware described under Subtest A was used without modification. A second cyclone train, without emission gas recirculation, was used for a "near-collocated" reference. This train used identical cyclone samplers equipped with a standard nozzle rather than the EGR nozzle. The remainder of the sampling train was conventional: a heated stainless steel probe, ice bath condenser, and a commercial Method 5 control box. Both probes (three sampling trains) were inserted at right angles to each other in order to sample at the same point in the duct (within approximately four-inch nozzle-to-nozzle spacing). The duct point and nozzle for the nonrecycle train which were selected resulted in an isokinetic flowrate that was slightly greater than the flowrate calculated for a $10\mu m$ D_{50} in the

cyclone. The isokinetic flowrate rather than the PM_{10} flowrate was used for sampling. The EGR cyclone was fitted with a smaller nozzle than the nonrecycle train. The EGR sample flowrate was adjusted to maintain isokinetic nozzle sampling. The recycle fraction was adjusted to make the cyclone flowrate identical to that used for the nonrecycle cyclone. The Method 17 sampler was operated in the usual fashion.

A total of eight valid EGR comparison tests were performed during the initial field test. Sampling runs 2 through 6 were completed as described under Subtest A. With the exception of Run 3, which was performed during a period of fluctuating boiler load, these were performed with the boiler at full load (56 MW). Runs 7 through 10 were replicates for Subtest B, all of which were run at minimum boiler conditions (28 MW).

The run parameters, along with the total mass and nominal PM_{10} loadings are shown in Table 4. The recycle rates (shown as percentage of the total cyclone flowrate) varied from 9.6% to 59.6% during the test series.

TEST NO. 2

The second EGR field test was carried out at a 500 MW coal-fired power plant. The plant consisted of two 250 MW units with emission from each unit controlled by two cold-side electrostatic precipitators. The sampling location chosen was between the outlet of one ESP and the stack. Pretest surveys indicated the duct velocity averaged 60 ft/sec, with substantial velocity spread. An aerosol mass median diameter in the 7-14 μm diameter range was expected. As previously mentioned, the cyclone trains used for the second field test were identical to those used for the first test (SoRI Cyclone I, Cyclone IV, and a 47 mm quartz-fiber backup filter). The EGR cyclone train simultaneously sampled a three-point traverse along with a standard sampling cyclone train following another candidate PM_{10} sampling protocol referred to as SIM5 (Synthetic Method 5).[8] The SIM5 protocol was developed to provide valid emissions data for 10μm and smaller particles while using a fixed sampling flowrate. The method is not capable of correctly measuring emissions of particles larger than 10μm, consequently no valid total emissions data can be obtained using it.

The flowrates through both trains were set to produce a 10 μm aerodynamic D_{50} through the first cyclone. The nonrecycle (SIM5) cyclone train sampled across the traverse at constant flowrate as outlined in the SIM5 protocol. By using a slightly smaller nozzle on the EGR system, the nozzle sampled isokinetically while the total cyclone flowrate was keep constant with the addition of variable amounts of recycle gas. Eight replicates of the paired measurements were initiated. However, equipment malfunctions invalidated the first two EGR runs, and the fifth EGR/SIM5 run was aborted after the boiler dropped from 240 MW to 90 MW due to plugging of a fuel feed line. The run parameters, total mass loadings, and PM_{10} mass loadings for these tests are shown in Table 5. As with the first field test, the samples were obtained within 10% of the isokinetic ratio. In this test series the recycle rates consistently averaged around 46%.

Table 4. EGR test 1 run parameters.

	Sample Flow (acfm)	Percent Recycle	Percent Isokinetic	Boiler Load (MW)	Mass Loading (mg/dNm^3)	PM_{10} Loading (mg/dNm^3)
Run 2						
M17	0.67	--	164.3	56	1557[a]	--
EGR	0.56	18.0	98.1		2053	453
Run 3						
M17	0.57	--	99.4	34	586	--
EGR	0.33	59.6	96.8		543	113
Run 4						
M17	0.40	--	96.1	56	2397	--
EGR	0.59	15.6	100.9		1952	391
Run 5						
M17	0.42	--	100.6	56	2077	--
EGR	0.62	15.7	107.5		1804	411
Run 6						
M17	0.48	--	107.7	56	1888	--
EGR	0.64	9.6	104.5		1808	399
Run 7						
M17	0.49	--	104.7	28	61.9	--
EGR	0.57	20.8	105.9		42.9	17.8
STD	0.66	--	89.7		46.5	18.5
Run 8						
M17	0.45	--	107.2		87.9	--
EGR	0.53	41.6	108.8	28	75.7	21.8
STD	0.67	--	102.7		57.2	21.8
Run 9						
M17	0.49	--	111.9		65.3	--
EGR	0.55	33.6	111.0	28	63.9	20.5
STD	0.74	--	107.9		67.0	28.8
Run 10						
M17	0.47	--	99.7		80.9	--
EGR	0.56	34.9	101.9	28	74.5	27.8
STD	0.74	--	100.6		60.4	26.6

[a]M17 control box malfunction--run deleted from test averages.

Table 5. EGR test 2 run parameters.

	Sample Flow (acfm)	Percent Recycle	Percent Isokinetic	Mass Loading (mg/dNm^3)	PM_{10} Loading (mg/dNm^3)
Run 1					
EGR	0.40	38.9	111.7	--[a]	110
SIM5	0.60	--	95.1	264	124
Run 2					
EGR	0.33	47.7	98.4	--[b]	--
SIM5	0.61	--	94.0	213	109
Run 3					
EGR	0.34	46.5	96.5	195	94
SIM5	0.62	--	97.3	201	107
Run 4					
EGR	0.35	46.3	99.7	279	130
SIM5	0.59	--	92.4	307	138
Run 6					
EGR	0.34	48.6	99.1	115	56
SIM5	0.61	--	100.2	130	66
Run 7					
EGR	0.34	47.5	99.6	200	86
SIM5	0.60	--	94.4	207	104
Run 8					
EGR	0.36	45.3	97.1	189	79
SIM5	0.60	--	91.7	228	104

[a]Excessive nozzle scrape -- total mass not included in test averages.

[b]Invalidated run -- deleted from test averages.

TEST NO. 3

The site chosen for the third EGR field test was a 221 MW coal-fired utility boiler. Sampling took place at the inlets to two identical particulate control devices. Eight four-inch ports provided access to the duct interior on each unit. The velocity of Duct A ranged from 37 to 64 ft/sec, with a mean velocity of approximately 51 ft/sec. Duct B had a velocity range of 45 to 61 ft/sec, with an average of 53 ft/sec.

The test plan called for a concurrent EGR/nonrecycle (SIM5) test series similar to that of Test No. 2. The flowrate for each train was chosen such that the aerodynamic D_{50} for the first cyclone was 10 μm. Across the traverse, the EGR nozzle sampled isokinetically while a constant cyclone flowrate was maintained using a variable fraction of recycle gas. The nonrecycle cyclone train once again sampled according to SIM5 protocol. In this test, full duct (12-point) PM_{10} measurements were performed rather than the three-point sample in Test 2. Each 12-point traverse involved sampling at three points in four of the eight ports. The eight ports available for sampling on each duct were grouped into two sets of four, ACEG and BDFH. Four sets of simultaneous EGR and nonrecycle (SIM5) runs were performed at the inlet to Unit A. Two traverses were performed in ports ACEG and two in ports BDFH. Two replicates were performed in Duct B using ports ACEG. The sampling hardware used for both the EGR and nonrecycle (SIM5) trains throughout this testing consisted of full SoRI Five-Stage Series Cyclone sets. The run parameters and loadings for the paired cyclone runs are shown in Table 6. The recycle rate averaged about 48% with little variation from run to run.

RESULTS AND CONCLUSIONS

Average particulate concentrations and 95% confidence limits from the data obtained in the three test series are summarized in Tables 7 and 8. As can be seen, the tests covered a broad range of particulate concentrations. At every site, the EGR train and the comparison device measured particulate concentrations which agreed within the combined confidence limits of the measurements. Table 7 also presents the relative standard deviation (standard deviation expressed as a percentage of the mean value) of each set of runs. In two cases the relative standard deviation of the EGR is over 15% (Site 1 at low load and Site 2). At Site 2 the same degree of variation is seen in measurements with comparison devices. Since the testing coincided with a period of coal pulverizer problems, the variability is easily attributable to source instability. Some indication of source variability was also noted at Site 1 at low load, although the variance of the EGR data is greater than that seen by the other techniques. It is also interesting to note that the precision of the PM_{10} measurements is better in every case than that of total mass measurements with the same device.

Table 6. EGR test 3 run parameters.

	Sample Flow (acfm)	Percent Recycle	Percent Isokinetic	Sampling Duct	Mass Loading (mg/dNm^3)	PM_{10} Loading (mg/dNm^3)
Run 1						
EGR	0.30	48.4	101.3	A	3630	744
SIM5	0.60	--	97.2	A	4090	776
Run 2						
EGR	0.31	47.9	100.8	A	3570	791
SIM5	0.58	--	99.4	A	2920	659
Run 3						
EGR	0.32	44.0	98.9	A	2740	749
SIM5	0.51	--	105.1	A	3750	650
Run 4						
EGR	0.30	48.4	101.6	A	3810	752
SIM5	0.57	--	98.5	A	3830	660
Run 5						
EGR	0.31	49.1	99.4	B	3830	814
SIM5	0.56	--	120.8	B	3270	756
Run 6						
EGR	0.31	52.2	101.1	B	4330	969
SIM5	0.57	--	105.9	B	3680	794

Table 7. Average particulate concentrations observed in EGR test series

	No. of Runs	Total Mass		PM_{10}	
		Average Loading (mg/dNm^3)	Relative Standard Deviation (%)	Average Loading (mg/dNm^3)	Relative Standard Deviation (%)
Site 1					
High boiler load					
M17 mass train	3	2120 (±638)[a]	12.1	--	--
EGR cyclone train	4	1904 (±192)	6.3	413 (±44)	6.7
Low boiler load					
M17 mass train	4	74 (±20)	16.8	--	--
EGR cyclone train	4	65 (±24)	23.4	22 (±6.7)	19.1
Std. cyclone train	4	57 (±12)	13.2	23 (±7.5)	19.7
Site 2					
EGR cyclone train	6	196 (±72)	29.7	92 (±26)	7.1
SIM5 cyclone train	7	221 (±51)	24.9	107 (±23)	6.4
Site 3					
EGR cyclone train	6	3650 (±546)	14.3	803 (±90)	10.7
SIM5 cyclone train	6	3590 (±444)	11.8	716 (±70)	9.3

[a] 95% confidence intervals are indicated for each mean particulate loading.

Table 8. Percentage difference between EGR cyclone train and reference device in paired runs.

	Number of Runs	Total Mass	PM_{10}
Site 1 (Method 17)	8	-11.5±8.3	--
Site 1 (Nonrecycle cyclone)	4	9.0±28.7	-8.3±27.4
Site 2 (SIM5 cyclone)	5	-9.3±8.4	-15±6.5
Site 3 (SIM5 cyclone)	6	1.6±20.0	11.4±9.7

[a]Quoted values represent the mean and 95 percent confidence limits of the difference between the EGR concentration and the comparison device concentration on individual runs, expressed as a percentage of the overall mean reference concentration.

The test plan for all three sites included simultaneous measurements (collocated where possible) with the EGR train and suitable comparison devices in order to minimize the effects of source temporal variability. Table 8 contains a paired run analysis of the test data. The entries in Table 8 represent means and 95 percent confidence limits of individual run percentage differences for the paired measurements of total particulate mass or PM_{10} concentration. The percentage differences between the EGR and SIM5 values are relative to the mean of the two concentrations. No consistent t end is seen between the EGR and comparison measurements, and the differences typically do not exceed the 95% significance level.

In summary, the EGR train continues to be a promising technique for source particulate measurements. Further developments of the technique include correction of the few design deficiencies discovered during these tests, adaptation of the EGR concept to a cascade impactor for more detailed size distribution measurements, and further field validation of the concept. It is believed that the method has excellent potential to satisfy the requirements of a PM_{10} reference method.

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APPENDIX A

APPLE BASIC COMPUTER PROGRAM

EGR SETUP 3.1

1.) Program Documentation
2.) Program Variables
3.) Sample Output
4.) Program Listing

EGR SETUP 3.1

EGR SETUP 3.1 is used to calculate and produce a run sheet for the Emission Gas Recycle (EGR) Sampling System. The program uses stack temperature and velocity variations to determine a matrix of target differential pressures (orifice ΔH, total LFE ΔP, and recycle ΔP) as a function of the given temperature and pitot P (velocity) ranges. The output table also includes the recycle gas percentage at each of the target flow conditions.

The program allows the operator to determine the total (cyclone) flowrate by either direct input or by specifying a desired particle size cut in the first cyclone (i.e. PM_{10}) and calculating the associated flowrate using appropriate calibration equations. The program then calculates the percent recycle required for each available nozzle size to maintain both isokinetic sampling and constant cyclone flowrate at average stack temperature and velocity conditions. The operator then chooses the nozzle which will successfully operate ($10 \leq$ Percent recycle ≤ 80) at the extreme stack conditions. Typically, the ideal nozzle will show a recycle rate of approximately 35 percent at average stack conditions. After nozzle selection, the programs begins the target ΔP matrix calculations, after which a hardcopy (paper) version is produced, if that option is chosen.

To execute the program insert the appropriate floppy disk into the #1 disk drive and enter "RUN EGR SETUP 3.1" followed by striking the "Return" key. This will load and begin execution of the program. The program will prompt the user, one question at a time, to either enter input data or respond to a given program option. After each response the user must depress the "Return" key before the computer will proceed with the next prompt. If the user incorrectly responds to a given prompt, the prompt will be restated and await the proper response. After all the input data has been entered, the user will be given the option to change any incorrect data.

HARDCOPY OPTION

A positive response (Y for yes) to this option will result in the output of a hardcopy (paper) version of the target ΔP matrix. A negative response (N for no) will simply scroll the matrix across the monitor. It must be noted at this point that because the output is formatted for an 80-column display, the video display will appear "wrapped around" the screen if it is setup for a 40-column display (as is usual).

INPUT DATA

The data input section of EGR SETUP 3.1 is roughly divided into three sections. The first section deals with test identification and location, the second concerns the various stack parameters, and the third involves the metering system calibration values. As mentioned earlier, the computer prompts the user one question at a time and will not proceed to the next input until the previous prompt has been satisfied.

Test Identification

1) Test ID Code. The ID code should uniquely identify a specific test run. The code should be no more than 25 characters in length, and contain no commas or apostrophies.

2) Test Date. The calendar date (and clock time, if desired) on which the identified test took place. The same character restrictions apply here as with the Test ID Code (and the following input strings).

3) Test Location. General or specific, process or site location at which the test took place (i.e. cement plant outlet, Black Eagle Power Station, etc.).

4) Operator(s). The name or (names) of the sampling system operator who completed the indicated test run.

Run Parameters

1) Min Stack Temperature (F). The minimum stack temperature, in degrees Fahrenheit (F), as previously determined. It is suggested that a slightly lower than actual value be entered to insure the target matrix will cover sufficient temperature variations.

2) Max Stack Temperature (F). The maximum expected stack temperature (F), as previously determined. Similarly to the minimum temperature, it is suggested to enter a value somewhat higher than the actual expected value.

3) Avg Stack Temperature (F). The previously determined average stack temperature (°F).

4) Min Stack Velocity (fps). The minimum expected velocity, in feet per second, as previously determined from a standard Method 2 velocity traverse. As with the temperature limits, it is recommended the lower limit be artificially extended.

5) Max Stack Velocity (fps). The maximum expected velocity, in feet per second, as determined by Method 2. Once again, the limit should be slightly extended past the actual maximum.

6) Avg Stack Velocity (fps). The average stack velocity, in feet per second, as determined from a previous Method 2 traverse. It should be noted that the velocity and temperature values may also be obtained from previous test data.

7) Barometric Pressure (in Hg). The local atmospheric pressure entered in units of inches of mercury.

8) Stack DP (in wg). The differential stack pressure, relative to ambient, expressed in inches of water gauge.

9) Meter Box Temperature (F). The estimated temperature (°F) of the EGR control box (i.e. dry gas meter, orifice, and LFE's).

10) Stack Moisture (%). The stack gas moisture content, estimated or previously determined, in percent.

11) Oxygen (%). That portion of the stack gas, expressed as a percentage, composed of oxygen.

12) Carbon Dioxide (%). That portion of the stack gas, expressed as a percentage, composed of carbon dioxide.

Cyclone Flowrate Option. This option allows the operator to either specify by responding with an "F" or have a flowrate calculated from a known calibration equation based on a desired size cut, PM_{10} for example, by responding with "D".

13) Total Flowrate (acfm). The specified, keyboard entry, total (cyclone) flowrate in actual feet per minute (at stack conditions).

14) Cyclone I D50 (microns). The specified, keyboard entry, D50 size cut of the first cyclone, expressed in microns.

System Calibration Values

1) Pitot Cp Value. The calibration coefficient for the colocated S-type pitot tube as determined by EPA Reference Method #2.

2) Orifice DH@ (in wg). The calibration factor ΔH@, defined as the orifice differential pressure which equates to 0.75 cfm at standard (528 R, 29.92 in Hg) conditions.

3) Total LFE "M" Value. The slope of the linear fit equation to the calibration data for the total LFE.

4) Total LFE "B" Value. The y-intercept of the linear fit equation to the calibration data for the total LFE.

5) Recycle LFE "M" Value. The slope of the linear fit equation to the calibration data for the recycle LFE.

6) Recycle LFE "B" value. The y-intercept of the linear fit equation to the calibration data for the recycle LFE.

Number of nozzles option. The operator should insert the number of nozzles which he considers probable for use at the given stack conditions. Due to time and space limitations, the operator should select no more than ten possible nozzles. After entering the number of possible nozzles the operator will be prompted to enter one at a time, the diameter, in inches, of each of the candidate nozzles.

INPUT DATA REVIEW

After all the data has been entered, the computer will display the entered data on three separate screens: the run parameters, the system calibration values, and the candidate nozzle diameters. The user will then be given the opportunity to change any mis-entered values. A prompt will appear at the bottom of the screen asking the user if a change is desired. If the response is "N", the program will proceed to the next data set. If the response is "Y", the user will be prompted to enter a numerical value indicating which data entry is to be changed. Another prompt will ask the user to enter the new, correct value. The corrected value will be added to the screen, and the user will be prompted again about changing a data entry. This sequence will continue until the data on all three screens has been checked. It should be noted, however, that once the operator has proceeded onto a new screen the old screen cannot be recalled without restarting the program.

NOZZLE SELECTION

As mentioned previously, the program uses the average stack conditions to determine which EGR nozzle best suits the desired application. After a short calculation period, a table will appear on the screen displaying the candidate nozzles, cyclone flowrates, and percent recycle gas required to meet the criteria of isokinetic sampling and constant cyclone flowrate. The selected nozzle should have a recycle rate of approximately 35% at average stack conditions. This assures the operability of the nozzle within a maximum range of recycle rates (10 to 80%). After the operator has numerically indicated the chosen nozzle, the computer will begin calculations for the target ΔP matrix output. Because of the large number of iterative calculations, the computer requires three to five minutes to complete the table. During this time the video screen will show a visual calculation indicator (an increasing series of dots).

As written for the Apple, EGR SETUP 3.1 uses a commercial machine language program called "BUILD USING", which is appended at the end of the program, for formatting text output to the screen and printer. Apple Computer Inc. did not include any form of the common "Print Using" capability found on most microcomputers. "BUILD USING" adds this capability. For translations of the programs to other machines, the calls to "BUILD USING" are as follows:

Call BU, output string, format string, expression and/or variable list.

output string = formatted result for printing
format string = string expression of format to be used.
expression and/or variable list = list of values (separated by commas) to be printed.

The output string is then printed by a simple Print statement. The Copyright for this program is owned by Rod Stover and it is marketed by Sensible Software, Inc., West Bloomfield, MI. It is used in EGR SETUP 3.1, in an undocumented form, with the permission of Sensible Software, Inc.

PROGRAM VARIABLES FOR EGR SETUP 3.1

Numeric Variables

AD(#) Nozzle area, ft^2
BR Calibration coefficient (y-intercept) for Recycle LFE
BT Calibration coefficient (y-intercept) for Total LFE
BU Build Using out format address
BW Stack gas moisture, percent
C(#) Input system calibration values
CP Pitot calibration coefficient (entered as C(1))
DF D_{50} Cut-point of Cyclone I, microns
EN Used for changing incorrectly entered data
FW Water fraction of mixed gas (@ cyclone), percent
HA Calibration variable (ΔH@) of controlling orifice, in H_2O
HO(#,#) Orifice pressure differential (ΔHo), in H_2O
HR(#,#) Recycle LFE Pressure differential (ΔP_R), in H_2O
HS "First guess" orifice pressure differential, in H_2O
HT(#,#) Total LFE pressure differential (ΔP_T), in H_2O
I(#) Input (keyboard) values
J Loop index
K Loop index
MD Dry molecular weight of stack gas
MR Calibration coefficient (slope) for Recycle LFE
MT Calibration coefficient (slope) for Total LFE
MW Wet molecular weight of stack gas
MW(#,#) Wet molecular weight of mixed gas (@ cyclone)
ND(#) Nozzle diameter, inches
NN Number of EGR nozzles
NZ Used for indicating desired nozzle
P Comparison ratio between Q_{total} and $Q_{cyclone}$
PC(#) Pitot pressure differential, in H_2O
PB Barometric pressure, in Hg
PC Carbon dioxide content of stack gas, percent
PK Stack pressure differential to ambient, in H_2O
PL(#) Percent recycle gas (for nozzle selection)
PN Minimum pitot pressure differential, in H_2O
PO Oxygen content of stack gas, percent
PP Pitot pressure differential increments, in H_2O
PR(#,#) Recycle gas fraction
PS Absolute stack pressure, in Hg
PX Maximum pitot pressure differential, in H_2O
Q1 Sample flowrate at meter conditions, acfm
Q2 Total flowrate at meter conditions, acfm
Q3 Recycle flowrate at meter conditions, acfm
QC(#,#) Total (cyclone) flowrate as a function of sample flow, acfm
QE(#) Recycle flowrate (for nozzle selection), acfm
QL(#) Total flowrate (for nozzle selection), acfm

Numeric Variables (continued)

QN(#) Sample flowrate (for nozzle selection), acfm
QR(#,#) Recycle flowrate at stack conditions, acfm
QS(#,#) Sample flowrate at stack conditions, acfm
QT Specified total flowrate, acfm
QT(#,#) Total (cyclone) flowrate as a function of D_{50}, acfm
T(#) Stack temperature, °F
TA Average stack temperature, °F
TM Meter temperature, °F
TN Minimum stack temperature, °F
TT Stack temperature increments, °F
TX Maximum stack temperature, °F
V(#,#) Stack gas velocity, ft/sec
VA Average stack gas velocity, ft/sec
VC(#,#) Stack gas viscosity, μpoise
VM Viscosity at meter box, μpoise
VN Minimum stack gas velocity, ft/sec
VS(#) Viscosity (for nozzle selection), μpoise
VX Maximum stack gas velocity, ft/sec
X Index and ratio of iteration
Z Index

String Variables

AG$	Blank space: Calculation indicator
BG$	Period: Calculation indicator
C1$	Pitot C_p: Input data review
C2$	ΔH@: Input data review
C3$	M (Total LFE): Input data review
C4$	B (Total LFE): Input data review
C5$	M (Recycle LFE): Input data review
C6$	B (Recycle LFE): Input data review
CG$	Asterik: Calculation indicator
CH$	Response input: SEt or calculate cyclone flowrate
CL$	D_{50} (microns): Input data review
D$	Program command
DT$	Date: Test data input
FC$	Response input: Entry change option
FM$	Cyclone flowrate: Input data review
GI$	% H_2O: Input data review
GJ$	% Oxygen: Input data review
GK$	% Carbon Dioxide: Input data review
ID$	Test ID Code: Test data input
JM$	Average velocity: Nozzle selection
JR$	D_{50} (microns): Nozzle selection
JT$	Selection parameters: Nozzle selection
LC$	Location: Test data input
ND$	Nozzle diameter: Input data review
OP$	Operators: Test data input
P$	Response input: Hardcopy option
PA$	Minimum velocity: Input data review
PB$	Maximum velocity: Input data review
PC$	Average velocity: Input data review
PD$	Barometric pressure: Input data review
PE$	Differential stack pressure: Input data review
R$	Program string: Build Using (formatted) output
TF$	Minimum stack temperature: Input data review
TG$	Maximum stack temperature: Input data review
TH$	Average stack temperature: Input data review
TM$	Meter temperature: Input data review
WA$	Average stack temperature: Hardcopy output
WB$	Average velocity, % H_2O, and dry molecular weight: Hardcopy output
WC$	Barometric pressure, % oxygen and molecular weight: Hardcopy output
WD$	Stack pressure and % carbon dioxide: Hardcopy output
WE$	Temperature range: Hardcopy output
WF$	Target ΔHo range: Hardcopy output
WG$	Target ΔP_T range: Hardcopy output
WH$	Target ΔP_R range: Hardcopy output
WI$	Target percent recycle: Hardcopy output
WJ$	Target ΔHo range: Hardcopy output
WL$	Target ΔP_T and ΔP_R range: Hardcopy output
WM$	Target percent recycle: Hardcopy output

EXHAUST GAS RECIRCULATION SETUP SHEET
VERSION 3.1 MAY 1986

TEST I.D. : CARB EGR1
RUN DATE : 1-15-86
LOCATION : GASSIFIER OUTLET
OPERATOR(S) : R.S.MARTIN
NOZZLE DIAMETER (IN) :.1853

STACK CONDITIONS:

AVERAGE TEMPERATURE (F) : 310.0
AVERAGE VELOCITY (FT/SEC) : 37.0
AMBIENT PRESSURE (IN HG) : 30.02
STACK PRESSURE (IN WG) : .00

GAS COMPOSITION
H2O = 16.0 %
O2 = 6.0 %
CO2 = 12.0 %

MD = 30.16
MW = 28.21
(LB/LB MOLE)

**** TARGET PRESSURE DROPS ****

DP(PTO)		TEMPERATURE (F) 250	261	272	283	294	306	317	328	339	350
0.213	SAMPLE	.86	.85	.83	.82	.81	.80	.79	.78	.77	
	TOTAL	1.62	1.63	1.63	1.64	1.65	1.65	1.66	1.67	1.68	
	RECYCLE	1.80	1.84	1.87	1.90	1.93	1.96	1.99	2.03	2.06	
	% RCL	42 %	42 %	43 %	44 %	44 %	45 %	45 %	46 %	46 %	
.227		.93	.92	.90	.89	.88	.86	.85	.84	.83	.82
		1.61	1.61	1.62	1.63	1.63	1.64	1.65	1.66	1.66	1.67
		1.69	1.72	1.75	1.79	1.82	1.85	1.88	1.92	1.95	1.98
		39 %	40 %	41 %	41 %	42 %	42 %	43 %	44 %	44 %	45 %
.241		.99	.97	.96	.94	.93	.92	.90	.89	.88	.87
		1.60	1.61	1.61	1.62	1.63	1.64	1.64	1.65	1.66	1.66
		1.60	1.64	1.67	1.71	1.74	1.77	1.81	1.84	1.87	1.90
		37 %	38 %	39 %	39 %	40 %	41 %	41 %	42 %	42 %	43 %
.255		1.04	1.03	1.01	1.00	.98	.97	.95	.94	.93	.91
		1.59	1.60	1.61	1.62	1.62	1.63	1.64	1.64	1.65	1.66
		1.53	1.56	1.60	1.63	1.67	1.70	1.73	1.77	1.80	1.83
		36 %	36 %	37 %	38 %	38 %	39 %	40 %	40 %	41 %	41 %
.269		1.10	1.08	1.07	1.05	1.04	1.02	1.01	.99	.98	.96
		1.59	1.60	1.60	1.61	1.62	1.62	1.63	1.64	1.65	1.65
		1.45	1.49	1.52	1.56	1.59	1.63	1.66	1.69	1.73	1.76
		34 %	35 %	35 %	36 %	37 %	37 %	38 %	39 %	39 %	40 %
.282		1.16	1.14	1.12	1.11	1.09	1.07	1.06	1.04	1.03	1.01
		1.58	1.59	1.60	1.60	1.61	1.62	1.63	1.63	1.64	1.65
		1.38	1.41	1.45	1.48	1.52	1.55	1.59	1.62	1.66	1.69
		32 %	33 %	34 %	34 %	35 %	36 %	36 %	37 %	38 %	38 %
.296		1.21	1.20	1.18	1.16	1.14	1.13	1.11	1.09	1.08	1.06
		1.57	1.58	1.59	1.60	1.60	1.61	1.62	1.63	1.63	1.64
		1.27	1.31	1.35	1.38	1.42	1.45	1.49	1.52	1.56	1.59
		30 %	30 %	31 %	32 %	33 %	33 %	34 %	35 %	35 %	36 %
.310		1.27	1.25	1.23	1.21	1.20	1.18	1.16	1.15	1.13	1.11
		1.57	1.58	1.58	1.59	1.60	1.61	1.61	1.62	1.63	1.64
		1.20	1.24	1.28	1.31	1.35	1.39	1.42	1.46	1.49	1.53
		28 %	29 %	30 %	30 %	31 %	32 %	33 %	33 %	34 %	35 %

(CONTINUED)

DP(PTO)	TEMPERATURE (F) 250	261	272	283	294	306	317	328	339	350
.324	1.33	1.31	1.29	1.27	1.25	1.23	1.21	1.20	1.18	1.16
	1.56	1.57	1.58	1.59	1.59	1.60	1.61	1.62	1.62	1.63
	1.13	1.17	1.21	1.25	1.28	1.32	1.36	1.39	1.43	1.46
	26 %	27 %	28 %	29 %	30 %	30 %	31 %	32 %	32 %	33 %
.338	1.39	1.36	1.34	1.32	1.30	1.28	1.27	1.25	1.23	1.21
	1.56	1.57	1.57	1.58	1.59	1.60	1.60	1.61	1.62	1.63
	1.07	1.10	1.14	1.18	1.22	1.26	1.29	1.33	1.37	1.40
	25 %	26 %	27 %	27 %	28 %	29 %	30 %	30 %	31 %	32 %
.352	1.44	1.42	1.40	1.38	1.36	1.34	1.32	1.30	1.28	1.26
	1.55	1.56	1.57	1.58	1.58	1.59	1.60	1.61	1.61	1.62
	1.00	1.04	1.08	1.12	1.16	1.19	1.23	1.27	1.30	1.34
	23 %	24 %	25 %	26 %	27 %	27 %	28 %	29 %	30 %	30 %
.365	1.50	1.48	1.45	1.43	1.41	1.39	1.37	1.35	1.33	1.31
	1.55	1.56	1.56	1.57	1.58	1.59	1.59	1.60	1.61	1.62
	.94	.98	1.02	1.05	1.09	1.13	1.17	1.21	1.24	1.28
	22 %	23 %	24 %	24 %	25 %	26 %	27 %	28 %	28 %	29 %
.379	1.56	1.53	1.51	1.49	1.46	1.44	1.42	1.40	1.38	1.36
	1.54	1.55	1.56	1.57	1.57	1.58	1.59	1.60	1.60	1.61
	.87	.91	.95	.99	1.03	1.07	1.11	1.15	1.18	1.22
	20 %	21 %	22 %	23 %	24 %	25 %	25 %	26 %	27 %	28 %
.393	1.61	1.59	1.56	1.54	1.52	1.50	1.47	1.45	1.43	1.41
	1.54	1.55	1.55	1.56	1.57	1.58	1.58	1.59	1.60	1.61
	.81	.85	.89	.93	.97	1.01	1.05	1.09	1.13	1.16
	19 %	20 %	21 %	22 %	22 %	23 %	24 %	25 %	26 %	26 %
.407	1.67	1.64	1.62	1.59	1.57	1.55	1.53	1.50	1.48	1.46
	1.53	1.54	1.55	1.56	1.57	1.57	1.58	1.59	1.60	1.60
	.75	.79	.83	.87	.91	.95	.99	1.03	1.07	1.11
	18 %	18 %	19 %	20 %	21 %	22 %	23 %	24 %	24 %	25 %
.421	1.73	1.70	1.67	1.65	1.62	1.60	1.58	1.56	1.53	1.51
	1.53	1.54	1.54	1.55	1.56	1.57	1.58	1.58	1.59	1.60
	.69	.73	.78	.82	.86	.90	.94	.97	1.01	1.05
	16 %	17 %	18 %	19 %	20 %	21 %	21 %	22 %	23 %	24 %

```
]LIST

5  REM     EGR SETUP PROGRAM
6  REM       VERSION 3.1 - RANDY MARTIN (MAY 1986) - SOUTHERN RES
EARCH INSTITUTE
7  REM
8  REM
10  HOME
20 D$ =  CHR$ (4)
24  REM
25  REM       DIMENSIONING VARIABLE ARRAYS
26  REM
30  DIM I(20): DIM T(20): DIM P(20): DIM C(20): DIM ND(12)
40  DIM V(20,12): DIM QS(20,12): DIM QC(20,12): DIM PR(20,12)
50  DIM FW(20,12): DIM VC(20,12): DIM QT(20,12): DIM QR(20,12)
60  DIM HO(20,12): DIM HT(20,12): DIM HR(20,12): DIM MW(20,12)
65  DIM AG$(200)
70  PRINT : INPUT "WOULD YOU LIKE A HARDCOPY OUTPUT? ";P$
80  IF P$ = "Y" GOTO 120
90  IF P$ = "N" GOTO 120
100  PRINT "Y OR N"
110  GOTO 70
114  REM
115  REM       DATA INPUT
116  REM
120  PRINT : INPUT "WHAT IS THE TEST I.D. CODE? ";ID$
130  INPUT "WHAT IS THE TEST DATE? ";DT$
140  INPUT "WHAT IS THE TEST LOCATION? ";LC$
150  INPUT "OPERATOR(S)? ";OP$
160  HOME
170  PRINT : PRINT "ENTER RUN PARAMETERS:"
180  PRINT : INPUT "      MIN STACK TEMPERATURE (F)? ";I(6)
190  INPUT "      MAX STACK TEMPERATURE (F)? ";I(7)
200  INPUT "      AVG STACK TEMPERATURE (F)? ";I(8)
210  INPUT "      MIN STACK VELOCITY (FPS)? ";I(1)
220  INPUT "      MAX STACK VELOCITY (FPS)? ";I(2)
230  INPUT "      AVG STACK VELOCITY (FPS)? ";I(3)
240  INPUT "      BAROMETRIC PRESSURE (IN HG)? ";I(4)
250  INPUT "      STACK DP (IN WG)? ";I(5)
260  INPUT "      METER BOX TEMPERATURE (F)? ";I(9)
270  INPUT "      STACK MOISTURE (%)? ";I(10)
280  INPUT "      OXYGEN (%)? ";I(11)
290  INPUT "      CARBON DIOXIDE (%)? ";I(12)
300  PRINT : INPUT "DO YOU WISH TO SET THE TOTAL FLOWRATE OR  SP
ECIFY A D50 FOR SRI CYCLONE I (F OR D)? ";CH$
310  IF CH$ = "F" GOTO 340
320  IF CH$ = "D" GOTO 360
330  GOTO 300
340  PRINT : INPUT "      TOTAL FLOWRATE (ACFM)? ";I(13)
350  GOTO 370
360  PRINT : INPUT "      CYCLONE I D50 (MICRONS)? ";I(13)
370  HOME : PRINT "SYSTEM CALIBRATION VALUES:": PRINT
380  INPUT "      PITOT CP VALUE? ";C(1)
390  PRINT : INPUT "      ORIFICE DH@ (IN WG)? ";C(2)
400  PRINT : INPUT "      TOTAL LFE 'M' VALUE? ";C(3)
410  INPUT "      TOTAL LFE 'B' VALUE? ";C(4)
420  PRINT : INPUT "      RECYCLE LFE 'M' VALUE? ";C(5)
```

```
430  INPUT "     RECYCLE LFE 'B' VALUE? ";C(6)
440  PRINT : PRINT : INPUT "NUMBER OF POSSIBLE NOZZLES (LIMIT 10
)? ";NN: PRINT
450  FOR K = 1 TO NN
460  PRINT "NOZZLE #";K;" DIA. (IN)  ": INPUT ND(K)
470  NEXT K
480  HOME
484  REM
485  REM       INPUT DATA REVIEW
486  REM
490  PRINT "  ::::::::::::::::::::::::::::::::::::"
500  PRINT "  :::::::::: VALUES ENTERED::::::::::"
510  PRINT "  ::::::::::::::::::::::::::::::::::::"
520 : PRINT "           VELOCITIES & PRESSURES"
530 PA$ = "              1) V(MIN) = ##<0#.##"
540 PB$ = "              2) V(MAX) = ##<0#.##"
550 PC$ = "              3) V(AVG) = ##<0#.##"
560 PD$ = "              4) P(BAR) = ##.##"
570 PE$ = "              5) P(STK) =>-#<0#.##"
580 TF$ = "              6) T(MIN) = ###.#"
590 TG$ = "              7) T(MAX) = ###.#"
600 TH$ = "              8) T(AVG) = ###.#"
610 TM$ = "              9) T(MTR) = ###.#"
620 GI$ = "             10) % H2O = #<0#.#"
630 GJ$ = "             11) % O2  = #<0#.##"
640 GK$ = "             12) % CO2 = #<0#.##"
650 CL$ = "             13) D50 = ##.##"
660 FM$ = "             13) Q(ACFM) = <0#.####"
665  GOSUB 63999
670  CALL BU,R$,PA$,I(1)
680  PRINT R$
690  CALL BU,R$,PB$,I(2)
700  PRINT R$
710  CALL BU,R$,PC$,I(3)
720  PRINT R$
730  CALL BU,R$,PD$,I(4)
740  PRINT R$
750  CALL BU,R$,PE$,I(5)
760  PRINT R$
770  PRINT "           TEMPERATURES"
780  CALL BU,R$,TF$,I(6)
790  PRINT R$
800  CALL BU,R$,TG$,I(7)
810  PRINT R$
820  CALL BU,R$,TH$,I(8)
830  PRINT R$
840  CALL BU,R$,TM$,I(9)
850  PRINT R$
860  PRINT "           GAS COMPOSITION"
870  CALL BU,R$,GI$,I(10)
880  PRINT R$
890  CALL BU,R$,GJ$,I(11)
900  PRINT R$
910  CALL BU,R$,GK$,I(12)
920  PRINT R$
930  PRINT "           CYCLONE I PARAMETERS"
940  IF CH$ = "D" GOTO 970
950  CALL BU,R$,FM$,I(13)
960  GOTO 980
970  CALL BU,R$,CL$,I(13)
```

```
980  PRINT R$: PRINT
990  INPUT "DO YOU WISH TO CHANGE AN ENTRY? ";FC$
1000  IF FC$ = "N" GOTO 1060
1010  IF FC$ = "Y" GOTO 1030
1020  PRINT "Y OR N": GOTO 990
1030  INPUT "WHICH ENTRY NUMBER? ";EN
1040  INPUT "WHAT IS THE NEW VALUE? ";I(EN)
1050  GOTO 480
1060  REM
1070 C1$ = "              1) CP(PTO) = #.###"
1080 C2$ = "              2) DH@(ORI) = ##.####"
1090 C3$ = "              3) M(T LFE) = #.#####"
1100 C4$ = "              4) B(T LFE) = #.#####"
1110 C5$ = "              5) M(R LFE) = #.#####"
1120 C6$ = "              6) B(R LFE) = #.#####"
1130  HOME : PRINT "  ::::::::::::::::::::::::::::::::::::::::"
1140  PRINT "  :::::::::: VALUES ENTERED:::::::::::"
1150  PRINT "  ::::::::::::::::::::::::::::::::::::::::": PRINT
1160  CALL BU,R$,C1$,C(1): PRINT R$: PRINT
1170  CALL BU,R$,C2$,C(2): PRINT R$: PRINT
1180  CALL BU,R$,C3$,C(3): PRINT R$
1190  CALL BU,R$,C4$,C(4): PRINT R$: PRINT
1200  CALL BU,R$,C5$,C(5): PRINT R$
1210  CALL BU,R$,C6$,C(6): PRINT R$: PRINT
1220  PRINT : INPUT "DO YOU WISH TO CHANGE AN ENTRY? ";FC$
1230  IF FC$ = "N" GOTO 1270
1240  IF FC$ = "Y" GOTO 1250
1245  PRINT "       Y OR N": GOTO 1220
1250  INPUT "WHICH ENTRY NUMBER? ";EN
1260  INPUT "WHAT IS THE NEW VALUE? ";C(EN): GOTO 1070
1270  HOME
1280  PRINT "  ::::::::::::::::::::::::::::::::::::::::"
1290  PRINT "  :::::::::: VALUES ENTERED:::::::::::"
1300  PRINT "  ::::::::::::::::::::::::::::::::::::::::": PRINT
1310  PRINT "           NOZZLE DIAMETERS (IN)"
1320 ND$ = "              ##); DIA (IN) = (0#.####"
1330  FOR K = 1 TO NN: CALL BU,R$,ND$,K,ND(K): PRINT R$: NEXT K
1340  PRINT : INPUT "DO YOU WISH TO CHANGE AN ENTRY? ";FC$
1350  IF FC$ = "N" GOTO 1380
1352  IF FC$ = "Y" GOTO 1360
1354  PRINT "       Y OR N": GOTO 1340
1360  INPUT "WHICH ENTRY NUMBER? ";EN
1370  INPUT "WHAT IS THE NEW VALUE? ";ND(EN): GOTO 1270
1374  REM
1375  REM       REDEFINIG VARIABLES
1376  REM
1380 VN = I(1):VX = I(2):VA = I(3):PB = I(4):PK = I(5):TM = I(9)

1390 TN = I(6):TX = I(7):TA = I(8):BW = I(10):PO = I(11):PC = I(
12)
1400 CP = C(1):HA = C(2):MT = C(3):BT = C(4):MR = C(5):BR = C(6)

1410  IF CH$ = "D" GOTO 1430
1420 QT = I(13): GOTO 1450
1430 DF = I(13)
1440  REM
1450  REM
1460  REM          STACK GAS PROPERTIES
1470  REM
1475  REM       DRY MOLECULAR WEIGHT
```

```
1476  REM
1480 MD = (32 * PO / 100) + (44 * PC / 100) + 28 * (1 - (PO / 10
0) - (PC / 100))
1484  REM
1485  REM       WET MOLECULAR WEIGHT
1486  REM
1490 MW = MD * (1 - BW / 100) + (18 * BW / 100)
1494  REM
1495  REM       ABSOLUTE STACK PRESSURE
1496  REM
1500 PS = PB + (PK / 13.6)
1509  REM
1510  REM       TARGET PARAMETERS (TEMPERATURE AND VELOCITY RANGE
S)
1511  REM
1520 PX = ((VX / (85.48 * CP)) ^ 2) * MW * PS / (TX + 460)
1530 PN = ((VN / (85.48 * CP)) ^ 2) * MW * PS / (TN + 460)
1540 TT = (TX - TN) / 9
1550 PP = (PX - PN) / 15
1560 T(1) = TN
1570 P(1) = PN
1580  FOR K = 1 TO 15
1590 Z = K + 1
1600 P(Z) = P(1) + (PP * K)
1610  NEXT K
1620  FOR K = 1 TO 9
1630 Z = K + 1
1640 T(Z) = T(1) + (TT * K)
1650  NEXT K
1660  REM
1670  REM
1680  REM       EGR NOZZLE SELECTION
1690  REM
1700  FOR K = 1 TO NN
1704  REM
1705  REM       NOZZLE AREA (FT2)
1706  REM
1710 AD(K) = 3.14159 * (ND(K) ^ 2.0) / 576
1714  REM
1715  REM       ISOKINETIC SAMPLE (NOZZLE) FLOWRATE
1716  REM
1720 QN(K) = AD(K) * VA * 60
1730 X = 0
1740 FW = BW / 100
1744  REM
1745  REM       VISCOSITY OF CYCLONE GAS
1746  REM
1750 VS(K) = 152.418 + (.25529 * TA) + (.000032355 * (TA ^ 2.0))
 - (74.143 * FW) + (53.147 * PO / 100)
1760  IF CH$ = "D" GOTO 1780
1770 QL(K) = QT: GOTO 1790
1774  REM
1775  REM       CYCLONE FLOWRATE AS A FUNCTION OF D50
1776  REM
1780 QL(K) = .072962 * ((MW * PS / (TA + 460)) ^  - .2949) * VS(
K) * (DF ^  - 1.4102)
1790 QE(K) = QL(K) - QN(K)
1800 PL(K) = QE(K) / QL(K)
1810 FW = FW * (1 - PL(K))
1820  IF FW < (BW / 100) GOTO 1840
```

```
1830 FW = BW / 100
1840 X = X + 1
1850  IF X < 7 GOTO 1750
1860  NEXT K
1864  REM
1865  REM       SCREEN FORMAT FOR NOZZLE SELECTION
1866  REM
1870 JMT$ = "      AVG VELOCITY (FT/SEC) = ###.##"
1880 JRT$ = "       CYCLONE I D50 (MICRONS) = ##.##"
1890 JTT$ = "#); <0#.####  ;  <0#.####  ;  <0#.####  ; -###.##"
1900  HOME
1910  PRINT : PRINT : PRINT : PRINT "  **************************
*************"
1920  PRINT "              NOZZLE  SELECTION"
1930  PRINT "  ************************************"
1940  PRINT
1950  CALL BU,R$,JMT$,VA
1960  PRINT R$: PRINT
1970  CALL BU,R$,JRT$,DF
1980  PRINT R$: PRINT
1990  PRINT "    NOZZLE     SAMPLE     CYCLONE"
2000  PRINT "     DIA.     FLOWRATE  FLOWRATE  PERCENT"
2010  PRINT "   (INCHES)    (ACFM)     (ACFM)   RECYCLE"
2020  PRINT
2030  FOR K = 1 TO NN
2040  CALL BU,R$,JTT$,K,ND(K),QN(K),QL(K),PL(K) * 100
2050  PRINT R$
2060  NEXT K
2070  PRINT : INPUT "WHICH NOZZLE? ";NZ
2080  HOME
2090 AG$ = "":BG$ = ".":CG$ = "*"
2100  REM
2110  REM
2120  REM      CALCULATING EGR TARGET FLOWS FOR TEMP. AND VELOCIT
Y RANGE
2130  REM
2135  HOME : VTAB 10: HTAB 15: PRINT "CALCULATING": PRINT
2140  FOR K = 1 TO 16
2160  FOR J = 1 TO 10
2180  VTAB 15: HTAB 10: PRINT "I = ";K;" OF 16": HTAB 10: PRINT
"J = ";J;" OF 10   "
2189  REM
2190  REM       CYCLONE GAS VISCOSITY
2191  REM
2200 V(K,J) = 85.48 * CP * (((T(J) + 460) * P(K) / (PS * MW)) ^
0.5)
2204  REM
2205  REM       SAMPLE (NOZZLE) FLOWRATE
2206  REM
2210 QS(K,J) = 0.32725 * V(K,J) * (ND(NZ) ^ 2.0)
2220 X = 1
2224  REM
2225  REM       ESTIMATED TOTAL FLOWRATE
2226  REM
2230 QC(K,J) = X * QS(K,J)
2234  REM
2235  REM       ESTIMATED RECYCLE RATIO (PERCENT)
2236  REM
2240 PR(K,J) = (X - 1) * QS(K,J) / QC(K,J)
2244  REM
```

```
2245  REM       CYCLONE GAS MOISTURE CONTENT
2246  REM
2250 FW(K,J) = (BW / 100) * (1 - PR(K,J))
2254  REM
2255  REM       CYCLONE GAS WET MOLECULAR WEIGHT
2256  REM
2260 MW(K,J) = MD * (1 - FW(K,J)) + (18 * (FW(K,J)))
2264  REM
2265  REM       CYCLONE GAS VISCOSITY
2266  REM
2270 VC(K,J) = 152.418 + (0.25529 * T(J)) + (0.000032355 * (T(J)
 ^ 2.0)) - (74.143 * FW(K,J)) + (53.147 * (PO / 100))
2280  IF CH$ = "D" GOTO 2310
2290 QT(K,J) = QT
2300  GOTO 2320
2304  REM
2305  REM       CYCLONE FLOWRATE AS A FUNCTION OF D50
2306  REM
2310 QT(K,J) = .072962 * ((MW(K,J) * PS / (T(J) + 460)) ^ ( - .2
949)) * VC(K,J) * (DF ^ ( - 1.4102))
2314  REM
2315  REM       RECYCLE FLOWRATE
2316  REM
2320 QR(K,J) = QT(K,J) * PR(K,J)
2324  REM
2325  REM       COMPARISON OF ESTIMATED AND CALCULATED CYCLONE (T
OTAL) FLOWRATES
2326  REM
2330 P = (QT(K,J) - QC(K,J)) / QT(K,J)
2340  IF  ABS (P) < 0.011 GOTO 2380
2350 X = QT(K,J) / QS(K,J)
2360  IF X > 0.1 GOTO 2230
2370 QS(K,J) = 0:QT(K,J) = 0:QR(K,J) = 0:PR(K,J) = 0
2380  REM
2390  REM
2400  REM
2410  REM
2420  REM       CONVERTING FROM STACK TO METER (AMBIENT) CONDITIO
NS
2430  REM
2440  REM
2444  REM
2445  REM       SAMPLE FLOWRATE @ METER CONDITIONS
2446  REM
2450 Q1 = QS(K,J) * (PS / PB) * ((TM + 460) / (460 + T(J))) * (1
 - BW / 100)
2454  REM
2455  REM       TOTAL (CYCLONE) FLOWRATE @ STACK CONDITIONS
2456  REM
2460 Q2 = QT(K,J) * (PS / (PB + 0.59)) * ((TM + 460) / (460 + T(
J))) * (1 - FW(K,J))
2464  REM
2465  REM       RECYCCLE FLOWRATE @ STACK CONDITIONS
2466  REM
2470 Q3 = QR(K,J) * (PS / (PB + 0.37)) * ((TM + 460) / (460 + T(
J)))
2480  REM
2490  REM
2500  REM     PRESSURE DROPS FROM FLOWRATES
2510  REM
```

```
2520  REM
2524  REM
2525  REM       VISCOSITY OF GAS AT LFE'S
2526  REM
2530 VM = 51.05 + (.207 * (460 + TM)) + (.0000324 * ((460 + TM) ^
2)) + (53.147 * (PO / 100))
2534  REM
2535  REM       INTIAL APPROXIMATION OF SAMPLE ORIFICE DIFFERENTI
AL PRESSURE
2536  REM
2540 HS = 31.3756 * HA * PB * (Q1 ^ 2) / (TM + 460)
2544  REM
2545  REM       SAMPLE ORIFICE TARGET PRESSURE DIFFERENTIAL
2546  REM
2550 HO(K,J) = 31.3756 * HA * (PB + (HS / 13.6)) * (Q1 ^ 2) / (T
M + 460)
2554  REM
2555  REM       TOTAL LFE TARGET PRESSURE DIFFERENTIAL
2556  REM
2560 HT(K,J) = (VM / 180.1) * (Q2 - BT) / MT
2565  REM       RECYCLE LFE TARGET PRESSURE DIFFERENTIAL
2570  IF Q3 > 0.0 GOTO 2590
2580 Q3 = 0.0
2584  REM
2586  REM
2590 HR(K,J) = (VM / 180.1) * (Q3 - BR) / MR
2600  NEXT J
2610  NEXT K
2620  REM
             2630  REM
             2640  REM      HARDCOPY OUTPU FORMATTED WITH BULD USING
             2650  REM
             2660  IF P$ = "N" GOTO 2680
             2670  PRINT D$;"PR#1"
             2680  PRINT  TAB( 24);"EXHAUST GAS RECIRCULATION SETUP SHEET"
2685  PRINT  TAB( 27);"VERSION 3.1   MAY 1986      "
2690  PRINT : PRINT "      TEST I.D. : ";ID$
2700  PRINT "      RUN DATE : ";DT$
2710  PRINT "      LOCATION : ";LC$
2720  PRINT "      OPERATOR(S) : ";OP$
2730  PRINT "      NOZZLE DIAMETER (IN) :";ND(NZ)
2740  PRINT : PRINT " STACK CONDITIONS:": PRINT
2750 WA$ = "     AVERAGE TEMPERATURE (F) : ###.#          GAS COMP
OSITION"
2760 WB$ = "     AVERAGE VELOCITY (FT/SEC) : ###.#      ;      H2O
= ##<0.# %    ;  MD = ##.##"
2770 WC$ = "     AMBIENT PRESSURE (IN HG) : ##.##       ;       O2
= ##<0.# %    ;  MW = ##.##"
2780 WD$ = "     STACK PRESSURE (IN WG) : >-##<0.##      ;       C
O2 = ##<0.# %        (LB/LB-MOLE)"
2790  CALL BU,R$,WA$,TA
2800  PRINT R$
2810  CALL BU,R$,WB$,VA,BW,MD
2820  PRINT R$
2830  CALL BU,R$,WC$,PB,PO,MW
2840  PRINT R$
2850  CALL BU,R$,WD$,PK,PC
2860  PRINT R$
2870  PRINT : PRINT : PRINT  TAB( 24);"**** TARGET PRESSURE DROP
S ****"
```

```
2880  PRINT : PRINT  TAB( 32);"TEMPERATURE (F)"
2890 WE$ = " DP(PTO)     ###   ;  ###   ;  ###   ;  ###   ;  ###   ;
###   ;  ###   ;  ###   ;  ###   ;  ###"
2900 WF$ = "  <0#.###   ; SAMPLE  ##<0.## ; ##<0.## ; ##<0.## ; #
#<0.## ; ##<0.## ; ##<0.## ; ##<0.## ; ##<0.## ; ##<0.##"
2910 WG$ = "            TOTAL  ##<0.## ; ##<0.## ; ##<0.## ; ##<0
.## ; ##<0.## ; ##<0.## ; ##<0.## ; ##<0.## ; ##<0.##"
2920 WH$ = "          RECYCLE ##<0.## ; ##<0.## ; ##<0.## ; ##<0
.## ; ##<0.## ; ##<0.## ; ##<0.## ; ##<0.## ; ##<0.##"
2930 WI$ = "           % RCL >-##<0# %; >-##<0# %; >-##<0# %; >-
##<0# %; >-##<0# %; >-##<0# %; >-##<0# %; >-##<0# %; >-##<0# %"
2940  CALL BU,R$,WE$,T(1),T(2),T(3),T(4),T(5),T(6),T(7),T(8),T(9
),T(10)
2950  PRINT R$: PRINT
2960  CALL BU,R$,WF$,P(1),HO(1,2),HO(1,3),HO(1,4),HO(1,5),HO(1,6
),HO(1,7),HO(1,8),HO(1,9),HO(1,10)
2970  PRINT R$
2980  CALL BU,R$,WG$,HT(1,2),HT(1,3),HT(1,4),HT(1,5),HT(1,6),HT(
1,7),HT(1,8),HT(1,9),HT(1,10)
2990  PRINT R$
3000  CALL BU,R$,WH$,HR(1,2),HR(1,3),HR(1,4),HR(1,5),HR(1,6),HR(
1,7),HR(1,8),HR(1,9),HR(1,10)
3010  PRINT R$
3020  CALL BU,R$,WI$,PR(1,2) * 100,PR(1,3) * 100,PR(1,4) * 100,P
R(1,5) * 100,PR(1,6) * 100,PR(1,7) * 100,PR(1,8) * 100,PR(1,9) *
100,PR(1,10) * 100
3030  PRINT R$: PRINT
3040 WJ$ = "  #<0.###   ;  ##<0.## ; ##<0.## ; ##<0.## ; ##<0.##
; ##<0.## ; ##<0.## ; ##<0.## ; ##<0.## ; ##<0.## ; ##<0.##"
3050 WL$ = "            ##<0.## ; ##<0.## ; ##<0.## ; ##<0.## ; #
#<0.## ; ##<0.## ; ##<0.## ; ##<0.## ; ##<0.## ; ##<0.##"
3060 WM$ = "           >-##<0# %; >-##<0# %; >-##<0# %; >-##<0# %
; >-##<0# %; >-##<0# %; >-##<0# %; >-##<0# %; >-##<0# %; >-##<0#
 %"
3070  FOR K = 2 TO 16
3080  CALL BU,R$,WJ$,P(K),HO(K,1),HO(K,2),HO(K,3),HO(K,4),HO(K,5
),HO(K,6),HO(K,7),HO(K,8),HO(K,9),HO(K,10)
3090  PRINT R$
3100  CALL BU,R$,WL$,HT(K,1),HT(K,2),HT(K,3),HT(K,4),HT(K,5),HT(
K,6),HT(K,7),HT(K,8),HT(K,9),HT(K,10)
3110  PRINT R$
3120  CALL BU,R$,WL$,HR(K,1),HR(K,2),HR(K,3),HR(K,4),HR(K,5),HR(
K,6),HR(K,7),HR(K,8),HR(K,9),HR(K,10)
3130  PRINT R$
3140  CALL BU,R$,WM$,PR(K,1) * 100,PR(K,2) * 100,PR(K,3) * 100,P
R(K,4) * 100,PR(K,5) * 100,PR(K,6) * 100,PR(K,7) * 100,PR(K,8) *
100,PR(K,9) * 100,PR(K,10) * 100
3150  PRINT R$: PRINT
3160  IF K <  > 8 GOTO 3220
3170  PRINT : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT
: PRINT : PRINT
3180  PRINT  TAB( 34);"(CONTINUED)": PRINT
3190  PRINT  TAB( 32);"TEMPERATURE (F)"
3200  CALL BU,R$,WE$,T(1),T(2),T(3),T(4),T(5),T(6),T(7),T(8),T(9
),T(10)
3210  PRINT R$: PRINT
3220  NEXT K
3230  PRINT D$;"PR#0"
3240  PRINT
3250  END
```

```
63999 BU =  PEEK (121) + 256 *  PEEK (122) + 286: CALL BU:BU =  PEEK
(6) + 256 *  PEEK (7): CALL BU + 3: RETURN : REM

==> DO NOT EDIT 63999.

65535  REM
  BUILDUSING (2.0)   APPENDED.

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==> TO REMOVE 'APPENDAGE', ENTER:
]EXEC BU.STRIP

]
```

APPENDIX B

APPLE BASIC COMPUTER PROGRAM

EGR REDUCTION 3.4

1.) Program Documentation
2.) Program Variables
3.) Sample Output
4.) Program Listing

EGR REDUCTION 3.4

EGR REDUCTION 3.4 is used to calculate run conditions and concentrations from sample runs using the Emission Gas Recycle (EGR) Sampling System. The program uses the various system parameters and particulate loadings to determine such factors as stack gas properties, isokinetic sampling ratio, sample (nozzle) flowrate, recycle gas flowrate, total (mixed or cyclone) flowrate, cyclone cutpoint, and system concentrations.

To execute the program, insert the correct floppy disk into the proper disk drive and enter "RUN EGR REDUCTION 3.4" followed by hitting the "Return" key. This will load and begin execution of the program. The program will then prompt the user, one question at a time, to either enter input data or respond to a particular program option (i.e. hardcopy output, save input file to disk, etc.). After the user has responded to a given prompt, the "Return" key must be depressed before the computer will proceed to the next prompt. Throughout the program, the various program options may be selected by responding with a "Y" for yes or an "N" for no (followed by "Return" in either case). If the user inadvertently enters a different response, the program will simply restate the option and await the correct response. If the user should enter a wrong value for the input data, he should continue entering data when prompted by the computer. After all the input data has been entered, the screen will show all of the entered data and give the user an option to change entered values at that time. After all the correct data has been entered, the program will calculate the test results and print a hardcopy version (if that option was chosen). Finally, the user will be given a choice of whether to save the input file to disk or simply clear the memory. Again, the response should be made in a way similar to the previous responses.

INITIAL PROGRAM OPTIONS

1) Existing file option. If the operator wishes to use a previously saved input file, respond by entering "Y". If the user wishes to enter a new input file, respond by entering "N". If the existing file option is executed, the computer will ask for the data file name. The operator enters the proper file name and the computer will load the file from the disk. The program will then continue as if all the data had been entered from the keyboard.

2) Hardcopy option. A positive response to this option will cause a hardcopy (paper) printout to be produced at the conclusion of the program calculations. A negative response will simply scroll the results across the monitor. It should be noted that because the output is formatted for an 80-column display, the video output may "wrap around" the screen if it is setup for a 40-column display.

INPUT DATA

The data input portion of EGR REDUCTION 3.4 is roughly divided into four sections, with the video screen being cleared before each. The first section concerns test identification and location, the second involves system

parameters recorded during the test run (temperatures, pressures, etc.), the third involves catch masses, blank weights, and moisture content, and the fourth concerns the system calibration values. As mentioned previously, the computer prompts the user one question at a time and will not present the next input until the previous one has been answered.

Test Identification

1) Test ID Code. The ID code should uniquely identify a specific test run. The code should be no more than 25 characters in length, and contain no commas or apostrophies. The same ID code will be used to identify the disk file should the input file be saved at the conclusion of the program.

2) Test Location. Identify the sampling location within the system process stream (i.e. venturi inlet, ESP outlet, etc.). The same character restrictions apply here as with the Test ID Code (and the following input strings).

3) Test Site. General or specific, process or site location (i.e. cement plant, Black Eagle Power Station, etc).

4) Test Date. The calendar date (and clock time, if desired) on which the identified test took place.

5) Operator(s). The name (or names) of the sampling system operator who completed the indicated test run.

System Parameters

1) Stack gas temperature (F). The average of the stack gas temperatures (in degrees Fahrenheit) recorded throughout the given sampling run.

2) Recycle temperature (F). The average of the recorded values for the temperature (°F) of the recycle gas as measured by the in-stack recycle thermocouple.

3) LFE Temperature (F). The average of the recorded values for the total LFE temperatures (°F). Although this value is measured at the inlet to the total LFE, it is also assumed as the temperature at the downstream recycle LFE.

4) DGM Temperature (F). The average value of the dry gas meter temperatures (°F) recorded throughout the duration of the sampling run.

5) DH Ori (in wg). The average value of the pressure drop from the controlling orifice with units in inches of water gauge.

6) DP Total LFE (in wg). The average value of the pressure differential across the laminar flow element (LFE) measuring the total mixed gas (cyclone) flowrate (inches H_2O).

7) P@ Inlet to LFE (in wg). The average value of the pressure (relative to ambient) measured at the inlet of the total LFE in inches of water gauge.

8) DP Recycle LFE (in wg). The average of the recorded values, again in inches of water gauge, for the pressure differential across the recycle LFE.

9) DP Pitot (in wg). The value entered here should be the average of the square root of the recorded pitot pressure differentials squared. More simply, sum the square roots of the individual ΔP's, divide by the total number of values, and square this resultant number. This number is the one to be entered as DP Pitot in inches of water gauge.

10) Barometric Pressure (in Hg). The local atmospheric pressure entered in absolute units of inches of mercury.

11) Stack DP (in wg). The differential stack pressure, relative ambient pressure, expressed as inches of water gauge.

12) DGM Volume (ft3). The volume of the gas sampled according to the dry gas meter for a given test run, expressed in cubic feet.

13) Run time (min). The duration of the given sampling run in minutes.

14) Stack Gas CO2 (%). That portion of the stack gas, expressed as a percentage, composed of carbon dioxide.

15) Stack Gas 02 (%). That portion of the stack gas, also in terms of percent, composed of oxygen.

16) EGR Nozzle Dia (in). The average diameter, as measured across at least three diameters, of the chosen EGR sampling nozzle expressed in inches.

Mass and Water Content

1) Cyclone 1 Catch (mg). The total particulate mass collected from the inside of the sampling nozzle and body of Cyclone 1, exluding any particulate matter which has entered the exit tube. The collected mass includes both brushed and rinsed (dried residue) particulate matter expressed in milligrams.

2) Backup Filter Catch (mg). The mass, in milligrams, collected on the surface of the filter and that recovered by brushing or rinsing the inside surfaces of the exit tube of cyclone 1 and the filter holder (upstream of the filter only).

NOTE: In situations where rinses or blanks were not performed, enter 0.0 milligrams for the catch weights from these sources.

3) Impinger Residue (mg). If impinger trains are used rather than condensers, it may be desirable to evaporate the impinger rinse to determine any condensable materials which may have been deposited. Enter the residue found in terms of milligrams deposited. If impingers were not used, simply enter 0.0 milligrams.

NOTE: A prompt will be displayed to determine if the impinger residue was measured. The operator's response will determine if condensable matter will be included in the hardcopy output.

4) Cyclone Rinse Blank (mg). Depending on the grade of the solvent used for rinses it may be advisable to evaporate a blank sample, the same volume used for each cyclone rinse, and determine any possible weight gain caused by solvent impurities. This value, entered in milligrams, will be subtracted from the raw weights of each cyclone catch.

5) Filter Holder Rinse Blank (mg). Similar to the cyclone rinse blank, this value, also in milligrams, is subtracted from the raw weight of the filter catch.

6) Filter Blank (mg). Since some flue gas conditions may adversely affect particular filter media, it may be necessary to run a "blank" filter to quantify these affects. Any weight change, negative or positive, should be entered in units of milligrams.

7) Impinger Wash Blank (mg). Similar to the other solvent blanks, except in proportion to the impinger wash volume, also entered in terms of milligrams.

Water Content Option. This option allows the operator to either estimate (by responding with an "E") or calculate (by responding with a "C") the moisture content of the stack gas.

8) Estimated Stack Moisture (%). The stack moisture, estimated or previously determined, in percent. This value is directly entered from the keyboard if the estimation option is chosen.

9) Condenser Catch (ml). The amount of water, in milliliters, collected within the ice chest condenser. This prompt only comes up if the "calculate" option is selected.

10) Drying Column Catch (gm). The net wet gain, in grams, of an in-line drying column containing a known, preweighed amount of dessicant (i.e. silica gel, calcium sulfate, etc.). As with the previous prompt, this only comes up if the "calculate" option is selected.

System Calibration Values

1) Cp Pitot. The calibration coefficient for the colocated S-type pitot tube as determined by EPA Reference Method #2.

2) DH@ Ori (in wg). The calibration factor ΔH@, defined as the orifice differential pressure required to produce a flowrate of 0.75 cfm at standard (528 °R, 29.92 in Hg) conditions.

3) M (Total LFE). The slope of a liner fit equation to the calibration data for the total LFE.

4) B (Total LFE). The y-intercept of a linear fit equation to the calibration data for the total LFE.

5) M (Recycle LFE). The slope of a linear fit equation to the calibration data for the recycle LFE.

6) B (Recycle LFE). The y-intercept of a linear fit equation to the calibration data for the recycle LFE.

7) DGM Gamma. The calibrated correction factor for the dry gas meter sample volume.

INPUT DATA REVIEW

After all the data has been entered, the computer will display on three separate screens the entered data. The user will then be given the opportunity to change any mis-entered values. A prompt will appear at the bottom of the screen asking the user if a change is desired. If the response is "N", the program will proceed to the next data set. If the response is positive, the user will be prompted to enter a numerical value indicating which data entry is to be changed. Another prompt will ask the user to enter the new, correct value. The corrected value will be added to the screen, and the user will be prompted again about changing a data entry. This sequence will continue until the data on all three screens has been checked. It must be noted, however, that once the operator has proceeded onto a new screen the old screen cannot be recalled without restarting the program. After all the input data has been corrected, the program will continue directly to the calculation of the results and the formatted output mentioned earlier.

FINAL PROGRAM OPTIONS

1) Disk File Option. Often times it is recommended that the input file be saved on a floppy disk file for future reference. By responding "Y" to the prompt, the input data is automatically saved to disk under the Test ID Code. A negative response will simply end the program.

As with the setup program, EGR REDUCTION 3.4 uses a commercial machine language program called "BUILD USING", which is appended at the end of the program, for formatting test output to the screen and printer. Apple Computer Inc. did not include any form of the common "Print Using" capability found on

most microcomputers. "BUILD USING" adds this capability. For translations of the programs to other machines, the calls to "BUILD USING" are as follows:

Call BU, output string, format string, expression and/or variable list.

output string = formatted result for printing
format string = string expression of format to be used.
expression and/or variable list = list of values (separated by commas) to be printed.

The output string is then printed by a simple Print statement. The Copyright for this program is owned by Rod Stover and it is marketed by Sensible Software, Inc., West Bloomfield, MI. It is used here in an undocumented form, with the permission of Sensible Software, Inc.

PROGRAM VARIABLES FOR EGR REDUCTION 3.4

Numeric Variables

A(#)	System input (keyboard) values
B(#)	Mass input (keyboard) values
BR	Calibration coefficient (y-intercept) for Recycle LFE
BT	Calibration coefficient (y-intercept) for Total LFE
BU	Build using output format address
BW	Stack gas moisture, percent
C(#)	Calibration input (keyboard) values
CD	Carbon dioxide content of stack gas, percent
CF	Corrected filter raw mass, mg
CI	Corrected impinger residue mass, mg
CM(#)	Corrected cyclone catch raw mass, mg
CN	Condenser (water) catch, ml
CP	Pitot calibration coefficient
CR	Cyclone rinse blank, mg
D(#)	Cyclone D_{50}, microns
DC	Drying column weight gain, mg
DF	Indicator (for use with file read option)
DH	Average orifice differential pressure, in H_2O
DS	Stack differential to ambient, in H_2O
EN	Used for changing incorrectly entered data
EW	Stack gas moisture, percent
FB	Filter blank, mg
FR	Filter holder rinse blank, mg
FW	Water fraction of mixed gas (@ cyclone), percent
GG	Gas meter correction factor (gamma)
HA	Calibration variable (ΔH@) of controlling orifice, in H_2O
IR	Impinger wash blank, mg
IS	Isokinetic sampling ratio, percent
K	Loop index
L(#)	Percent less than (of weight)
M(#)	Cyclone catch, mg
MD	Dry molecular weight of stack gas
MF	Mass gain of filter, mg
MI	Mass of impinger residue, mg
MM	Wet molecular weight of mixed gas
MR	Calibration coefficient (slope) for Recycle LFE
MT	Calibration coefficient (slope) for Total LFE
MV	Gas meter volume, ft^3
MW	Wet molecular weight of stack gas
ND	Nozzle diameter, inches
O2	Oxygen percentage in stack gas
OT	Overall total mass collected, mg
PB	Barometric pressure, in Hg
PI	Relative pressure at inlet to Total LFE, in H_2O
PL	Average Total LFE differential pressure, in H_2O
PP	Squared average square root of pitot ΔP,(($\sqrt{\Delta P}$)↑2),in H_2O

Numeric Variables (continued)

PR	Average Recycle LFE differential pressure, in H_2O
PS	Absolute stack pressure, in Hg
PT	Total particulate mass, mg
QR	Average recycle flowrate (@ stack conditions), acfm
QS	Average sample flowrate (@ stack conditions), acfm
QT	Average total flowrate (@ stack conditions), acfm
RP	Average percent recycle
RT	Run time, min
SV	Sample volume (@ STD conditions), scf
TL	Average LFE temperature, °F
TM	Average dry gas meter temperature, °F
TR	Average recycle gas temperature (@ stack), °F
TS	Average stack gas temperature, °F
UL	Viscosity of gas at LFE, µpoise
UM	Viscosity of mixed gas (@ cyclone), µpoise
V1	Volume of condenser water (@ STD conditions), scf
V2	Volume of drying column water (@ STD conditions), scf
VS	Average stack gas velocity, ft/sec
W(#)	Cyclone loading, mg/dncm
WF	Filter loading, mg/dncm
WI	Impinger residue loading, mg/dncm
WO	Overall loading, mg/dncm
WP	Particulate total loading, mg/dncm
X(#)	Cyclone loading, gr/acf
XF	Filter loading, gr/acf
XI	Impinger residue loading, gr/acf
XO	Overall loading, gr/acf
XP	Particulate total loading, gr/acf
Y(#)	Cyclone loading, gr/dscf
YF	Filter loading, gr/dscf
YI	Impinger residue loading, gr/dscf
YO	Overal loading, gr/dscf
YP	Particulate total loading, gr/dscf
Z(#)	Cyclone loading, lb/dscf
ZF	Filter loading, lb/dscf
ZI	Impinger residue loading, lb/dscf
ZO	Overall loading, lb/dscf
ZP	Particulate total loading, lb/dscf

String Variables

A1$ Stack temperature, orifice ΔH, and barometric pressure: Hardcopy output
A2$ Cyclone parameters and concentrations: Hardcopy output
AA$ Stack temperature and orifice ΔH: Input data review
AB$ Cyclone 1 mass and cyclone wash blank: Input data review
AC$ Pitot Cp: Input data review
AN$ Response input: Read file option
B1$ Recycle temperature, ΔP total LFE, and ΔP stack: Hardcopy output
B2$ Backup filter concentrations: Hardcopy output
BA$ Recycle temperature and total LFE ΔP: Input data review
BB$ Cyclone 2 mass: Input data review
BC$ ΔH@: Input data review
C1$ LFE Temperature, LFE inlet pressure, and DGM volume: Hardcopy output
C2$ Particulate loading totals: Hardcopy output
CA$ LFE Temperature and LFE inlet pressure: Input data review
CB$ Cyclone 3 mass and filter holder wash: Input data review
CC$ M (Total LFE): Input data review
D$ Program command
D1$ Gas meter temperature, ΔP recycle LFE, and run time: Hardcopy output
D2$ Condensable (impinger residue) concentration: Hardcopy output
DA$ Gas meter temperature and ΔP recycle LFE: Input data review
DB$ Cyclone 4 mass and filter blank: Input data review
DC$ M (Total LFE): Input data review
E1$ ΔP pitot and % carbon dioxide: Hardcopy output
E2$ Overall catch concentrations: Hardcopy output
EA$ ΔP pitot: Input data review
EB$ Cyclone 5 mass: Input data review
EC$ M (Total LFE): Input data review
F1$ % Oxygen: Hardcopy output
FA$ Barometric pressure: Input data review
FB$ Filter mass and impinger wash blank: Input data review
FC$ B (Recycle LFE): Input data review
FS$ Response input: Input file save option
G1$ Nozzle diameter: Hardcopy output
GA$ Differential stack pressure: Input data review
GB$ Impinger residue mass: Input data review
GC$ Gas meter correction factor (gamma): Input data review
H1$ Estimated water content, cyclone 1 mass, and cyclone rinse: Hardcopy output
HA$ Gas meter volume: Input data review
HB$ Estimated stack gas water content: Input data review
HC$ Response input: Hardcopy output option
I1$ Cyclone 2 mass: Hardcopy output
IA$ Run time: Input data review
IB$ Condenser water volume: Input data review
ID$ Test ID Code: Test data input
IR$ Impinger residue prompt: Determines partial output format
J1$ Condenser volume, cyclone 3 mass, and filter rinse: Hardcopy output
JA$ % Carbon dioxide: Input data review
JB$ Drying column weight gain: Input data review

String Variables (continued)

K1$	Drying column, cyclone 4 mass, and filter blank: Hardcopy output
KA$	% Oxygen: Input data review
L1$	Cyclone 5 mass: Hardcopy output
LA$	Nozzle diameter: Input data review
LO$	Location: Test data input
M1$	Filter mass gain and impinger rinse blank: Hardcopy output
N1$	Pitot Cp: Hardcopy output
NN$	Response Input: File name change
O1$	ΔH@: Hardcopy output
OP$	Operators: Test data input
P1$	M (Total LFE) and Impinger residue mass: Hardcopy output
Q1$	B (Total LFE): Hardcopy output
R$	Program string: Build Using (formatted) output
R1$	M (Recycle LFE): Hardcopy output
S1$	B (Recycle LFE): Hardcopy output
S2$	Gas meter correction factor (gamma): Hardcopy output
T1$	Stack velocity: Hardcopy output
TD$	Test Date: Test data input
TS$	Test Site: Test data input
U1$	Stack gas moisture: Hardcopy output
V1$	Sample flowrate (@ stack): Hardcopy output
VC$	Response input: Entry change option
VE$	Values entered: Hardcopy output
W1$	Total flowrate (@ stack): Hardcopy output
WC$	Response input: Water content estimate or calculate
X1$	Recycle flowrate (@ stack): Hardcopy option
Y1$	Percent recycle: Hardcopy option
Z1$	Isokinetic ratio: Hardcopy option

EXHAUST GAS RECIRCULATION
DATA REDUCTION
VERSION 3.4 MAY 1986

TEST ID. CODE: CARB EGR1 (V3.4)
TEST LOCATION: GASSIFIER OUTLET
TEST SITE: SACRAMENTO/CALIFORNIA
TEST DATE: 1-15-86
OPERATOR(S): R.S.MARTIN

***** ENTERED RUN DATA *****

TEMPERATURES
T(STK): 310.1 F
T(RCL): 323.4 F
T(LFE): 60.9 F
T(DGM): 56.6 F

SYSTEM PRESSURES
DH(ORI): 1.14 INWG
DP(TOT): 1.69 INWG
P(INL) : 5.23 INWG
DP(RCL): 1.69 INWG
DP(PTO): 0.30 INWG

MISCELLANEA
P(BAR) : 30.02 INHG
DP(STK): 0.00 INWG
V(DGM) : 10.007 FT3
TIME : 42.00 MIN
% CO2 : 12.10
% O2 : 6.30
NOZ (IN): 0.1853

WATER CONTENT
ESTIMATE : 16.9 %
OR
CONDENSER: 0.0 ML
COLUMN : 0.0 GM

RAW MASSES
CYCLONE 1: 12.5 MG
FILTER : 237.4 MG
IMPINGER
RESIDUE : 0.0 MG

BLANK VALUES
CYC RINSE : 0.0 MG
FILTER HOLDER
RINSE : 0.0 MG
FILTER BLANK : 0.0 MG
IMPINGER
RINSE : 0.0 MG

CALIBRATION VALUES
CP(PITOT) : 0.830
DH@(ORI) : 10.980
M(TOT LFE): 0.2298
B(TOT LFE): -.0058
M(RCL LFE): 0.0948
B(RCL LFE): -.0007
DGM GAMMA : 0.9940

****** REDUCED DATA ******

STACK VELOCITY (FT/SEC)	37.11
STACK GAS MOISTURE (%)	16.9
SAMPLE FLOWRATE (ACFM)	0.4263
TOTAL FLOWRATE (ACFM)	0.6756
RECYCLE FLOWRATE (ACFM)	0.2506
PERCENT RECYCLE	36.9
ISOKINETIC RATIO (%)	102.2

	(UM)	(% <)	(MG/DNCM)	(GR/ACF)	(GR/DCF)	(LB/DSCF) (X 1E6)
	(PARTICULATE)					
CYCLONE 1	9.37	95.0	43.2	0.01075	0.01882	2.69457
BACKUP FILTER	---	---	819.6	0.20420	0.35742	51.175
PARTICULATE TOTAL	---	---	862.8	0.21495	0.37623	53.870

```
]LIST

5  REM       EXHAUST GAS RECIRCULATION (EGR) DATA REDUCTION PROGR
AM
6  REM              RANDY MARTIN - SOUTHERN RESEARCH INSTITUTE (M
AY 1986)
7  REM                          VERSION 3.4
8  REM        AMMENDED FROM 3.0     2-25-86 R.S.MARTIN
9  REM
10  DIM A(20): DIM B(20): DIM C(20)
20  DIM ID$(50): DIM LO$(50): DIM TS$(50): DIM TD$(50): DIM OP$(
50)
30 D$ =  CHR$ (4)
40  REM
50  REM       READING AN EXISTING FILE FROM DISK
60  HOME
70  VTAB (10): PRINT "DO YOU WISH TO USE AN EXISTING FILE? ";: GET
AN$: PRINT AN$
80  IF AN$ = "Y" GOTO 110
90  IF AN$ = "N" GOTO 190
100  PRINT "         Y OR N": GOTO 70
110  PRINT : INPUT "FILE ID CODE: ";ID$
120  PRINT D$;"OPEN" + ID$
130  PRINT D$;"READ" + ID$
140  INPUT ID$: INPUT LO$: INPUT TS$: INPUT TD$: INPUT OP$: INPUT
WC$
150  FOR K = 1 TO 16: INPUT A(K): NEXT K
160  FOR K = 1 TO 9: INPUT B(K): NEXT K
170  FOR K = 1 TO 7: INPUT C(K): NEXT K
175  INPUT IR$
180  PRINT D$;"CLOSE" + ID$:DF = 1
190  HOME
200  REM        HARDCOPY OPTION
210  VTAB (10): PRINT " WOULD YOU LIKE A HARDCOPY OUTPUT? ";: GET
HC$: PRINT HC$
220  IF HC$ = "N" GOTO 270
230  IF HC$ = "Y" GOTO 270
240  PRINT "         Y OR N": GOTO 200
250  REM
260  REM
270  REM       KEYBOARD INPUTS
280  REM
290  REM
300  IF DF = 1 GOTO 800
310  HOME : PRINT "INPUT TEST ID INFORMATION. . . ": PRINT
320  INPUT "TEST ID CODE: ";ID$
330  INPUT "TEST LOCATION: ";LO$
340  INPUT "TEST SITE: ";TS$
350  INPUT "TEST DATE: ";TD$
360  INPUT "OPERATOR(S): ";OP$
370  HOME : PRINT "ENTER AVERAGE RUN DATA": PRINT
380  INPUT "STACK TEMPERATURE (F): ";A(1)
390  INPUT "RECYCLE TEMPERATURE (F): ";A(2)
400  INPUT "LFE TEMPERATURE (F): ";A(3)
410  INPUT "DGM TEMPERATURE (F): ";A(4)
420  PRINT : INPUT "DH ORI (IN WG): ";A(5)
430  INPUT "DP TOTAL LFE (IN WG): ";A(6)
```

```
440  INPUT "P @ INLET TO LFE (IN WG): ";A(7)
450  INPUT "DP RECYCLE LFE (IN WG): ";A(8)
460  INPUT "DP PITOT (IN WG): ";A(9)
470  PRINT : INPUT "BAROMETRIC PRESSURE (IN HG): ";A(10)
480  INPUT "STACK DP (IN WG): ";A(11)
490  INPUT "DGM VOLUME (FT3): ";A(12)
500  INPUT "RUN TIME (MIN): ";A(13)
510  INPUT "STACK GAS CO2 (%): ";A(14)
520  INPUT "STACK GAS O2 (%): ";A(15)
530  INPUT "EGR NOZZLE DIA (IN): ";A(16)
540  HOME : PRINT "RAW MASS DATA": PRINT "(ENTER ZERO FOR VALUES
 NOT MEASURED)": PRINT : INPUT "CYCLONE 1 CATCH (MG): ";B(1)
590  INPUT "BACKUP FILTER CATCH (MG): ";B(2)
600  INPUT "IMPINGER RESIDUE (MG): ";B(3)
604  PRINT
605  INPUT "IMPINGER RESIDUE MEASURED (Y OR N)? ";IR$
610  PRINT : INPUT "CYCLONE RINSE BLANK (MG): ";B(4)
620  INPUT "FILTER HOLDER RINSE BLANK (MG): ";B(5)
630  INPUT "FILTER BLANK (MG): ";B(6)
635  PRINT
640  INPUT "IMPINGER WASH BLANK (MG): ";B(7)
643  IF IR$ = "Y" OR IR$ = "N" GOTO 650
644  GOTO 642
650  PRINT : INPUT "ESTIMATE OR CALCULATE STACK GAS MOISTURE CON
TENT (E OR C)? ";WC$
660  IF WC$ = "E" GOTO 690
670  IF WC$ = "C" GOTO 700
680  GOTO 650
690  PRINT : INPUT "  ESTIMATED STACK MOISTURE (%): ";B(8):B(9) =
0: GOTO 720
700  PRINT : INPUT "  CONDENSER CATCH (ML): ";B(8)
710  INPUT "  DRYING COLUMN CATCH (GM): ";B(9)
720  HOME : PRINT "ENTER SYSTEM CALIBRATION VALUES": PRINT
730  INPUT "CP PITOT: ";C(1): PRINT
740  INPUT "DH@ ORI (IN WG): ";C(2)
750  PRINT : INPUT "M (TOTAL LFE): ";C(3)
760  INPUT "B (TOTAL LFE): ";C(4)
770  PRINT : INPUT "M (RECYCLE LFE): ";C(5)
780  INPUT "B (RECYCLE LFE): ";C(6)
790  PRINT : INPUT "DGM GAMMA: ";C(7)
800 AA$ = "  1)T(STK) = ##<0#.#  ; 5)DH(ORI) = #<0#.##"
810 BA$ = "  2)T(RCL) = ##<0#.#  ; 6)DP(TOT) = #<0#.##"
820 CA$ = "  3)T(LFE) = ##<0#.#  ; 7)P(INL)  = #<0#.##"
830 DA$ = "  4)T(DGM) = ##<0#.#  ; 8)DP(RCL) = #<0#.##"
840 EA$ = "9)DP(PTO) = #<0#.##"
850 FA$ = "10)P(BAR)   =  #<0#.##"
860 GA$ = "11)DP(STK)  =  #<0#.##"
870 HA$ = "12)V(DGM)   = ##<0#.###"
880 IA$ = "13)RUN TIME = ##<0#.###"
890 JA$ = "14)% CO2    =  #<0#.##"
900 KA$ = "15)% O2     =  #<0#.##"
910 LA$ = "16)NOZ (IN) =   <0#.####"
920 AB$ = "  1)CYC 1  = ###<0#.# ; 4)CYC WASH = ##<0#.#"
930 BB$ = "  2)FILTER = ###<0#.#  5)FILTER HOLDER"
940 CB$ = "  3)IMP RES= ###<0#.#    ;    WASH = ##<0#.#"
950 DB$ = "                        6)FILTER   = ##<0#.#"
960 EB$ = "                        7)IMPINGER"
970 FB$ = "                              WASH = ##<0#.#"
980 GB$ = "  "
990 HB$ = " 8)ESTIMATED (%) = ##<0#.#"
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```
1000 IB$ = " 8)CONDENSER(ML)= ##<0#.#"
1010 JB$ = " 9)COLUMN (GM)  = ##<0#.#"
1020 AC$ = "   1)CP(PITOT)  = <0#.###"
1030 BC$ = "   2)DH@(ORI)   = #<0#.###"
1040 CC$ = "   3)M(TOT LFE) = <0#.####"
1050 DC$ = "   4)B(TOT LFE) = <0#.####"
1060 EC$ = "   5)M(RCL LFE) = <0#.####"
1070 FC$ = "   6)B(RCL LFE) = <0#.####"
1080 GC$ = "   7)DGM GAMMA  = <0#.####"
1090  REM
1100  REM
1110  REM           ENTERED DATA REVIEW
1120  REM
1130  REM
1135  GOSUB 63999
1140 VE$ = " ********** VALUES ENTERED **********"
1150  HOME : PRINT VE$: PRINT
1160  PRINT " TEMPERATURES (F)   PRESSURES (INWG)"
1170  CALL BU,R$,AA$,A(1),A(5): PRINT R$
1180  CALL BU,R$,BA$,A(2),A(6): PRINT R$
1190  CALL BU,R$,CA$,A(3),A(7): PRINT R$
1200  CALL BU,R$,DA$,A(4),A(8): PRINT R$
1210  CALL BU,R$,EA$,A(9): PRINT  TAB( 22);R$
1220  PRINT : PRINT  TAB( 10);"MISCELLANEA"
1230  CALL BU,R$,FA$,A(10): PRINT  TAB( 11);R$
1240  CALL BU,R$,GA$,A(11): PRINT  TAB( 11);R$
1250  CALL BU,R$,HA$,A(12): PRINT  TAB( 11);R$
1260  CALL BU,R$,IA$,A(13): PRINT  TAB( 11);R$
1270  CALL BU,R$,JA$,A(14): PRINT  TAB( 11);R$
1280  CALL BU,R$,KA$,A(15): PRINT  TAB( 11);R$
1290  CALL BU,R$,LA$,A(16): PRINT  TAB( 11);R$: PRINT
1300  PRINT "DO YOU WISH TO CHANGE AN ENTRY? ";: GET VC$: PRINT
VC$
1310  IF VC$ = "Y" GOTO 1340
1320  IF VC$ = "N" GOTO 1370
1330  PRINT "       (Y OR N)": GOTO 1300
1340  INPUT "WHICH ENTRY NUMBER? ";EN
1350  IF EN > 16 GOTO 1340
1360  INPUT "WHAT IS THE NEW VALUE? ";A(EN): GOTO 1140
1370  HOME : PRINT VE$: PRINT
1380  PRINT " RAW MASSES (MG)    SYSTEM BLANKS (MG)"
1390  CALL BU,R$,AB$,B(1),B(4): PRINT R$
1400  CALL BU,R$,BB$,B(2): PRINT R$
1410  CALL BU,R$,CB$,B(3),B(5): PRINT R$
1420  CALL BU,R$,DB$,B(6): PRINT R$
1430  PRINT  TAB( 22);"7)IMPINGER"
1440  CALL BU,R$,FB$,B(7): PRINT R$
1450  CALL BU,R$,GB$: PRINT R$
1460  PRINT : PRINT  TAB( 8);"MOISTURE CONTENT (METH 4)"
1470  IF WC$ = "C" GOTO 1490
1480  CALL BU,R$,HB$,B(8): PRINT  TAB( 10);R$: GOTO 1510
1490  CALL BU,R$,IB$,B(8): PRINT  TAB( 10);R$
1500  CALL BU,R$,JB$,B(9): PRINT  TAB( 10);R$
1510  PRINT : PRINT "DO YOU WISH TO CHANGE AN ENTRY? ";: GET VC$
: PRINT VC$
1520  IF VC$ = "Y" GOTO 1550
1530  IF VC$ = "N" GOTO 1580
1540  PRINT "          (Y OR N)": GOTO 1510
1550  INPUT "WHICH ENTRY NUMBER? ";EN
1560  IF EN > 13 GOTO 1550
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1570  INPUT "WHAT IS THE NEW VALUE? ";B(EN): GOTO 1370
1580  HOME : PRINT VE$: PRINT
1590  PRINT "  CALIBRATION VALUES": PRINT
1600  CALL BU,R$,AC$,C(1): PRINT R$: PRINT
1610  CALL BU,R$,BC$,C(2): PRINT R$: PRINT
1620  CALL BU,R$,CC$,C(3): PRINT R$
1630  CALL BU,R$,DC$,C(4): PRINT R$: PRINT
1640  CALL BU,R$,EC$,C(5): PRINT R$
1650  CALL BU,R$,FC$,C(6): PRINT R$: PRINT
1660  CALL BU,R$,GC$,C(7): PRINT R$: PRINT
1670  PRINT "DO YOU WISH TO CHANGE AN ENTRY? ";: GET VC$: PRINT
VC$
1680  IF VC$ = "Y" GOTO 1710
1690  IF VC$ = "N" GOTO 1760
1700  PRINT "          (Y OR N)": GOTO 1670
1710  INPUT "WHICH ENTRY NUMBER? ";EN
1720  IF EN > 7 GOTO 1710
1730  INPUT "WHAT IS THE NEW VALUE? ";C(EN): GOTO 1580
1740  REM
1750  REM
1760  REM            REASSIGNING VARIABLES
1770  REM
1780  REM
1790 TS = A(1):TR = A(2):TL = A(3):TM = A(4)
1800 DH = A(5):PL = A(6):PI = A(7):PR = A(8):PP = A(9)
1810 PB = A(10):DS = A(11):MV = A(12):RT = A(13):CD = A(14):02 =
A(15):ND = A(16)
1820 M(1) = B(1):MF = B(2)
1830 MI = B(3):CR = B(4):FR = B(5):FB = B(6):IR = B(7)
1840 CP = C(1):HA = C(2):MT = C(3):BT = C(4):MR = C(5):BR = C(6)
:GG = C(7)
1850  IF WC$ = "C" GOTO 1870
1860 BW = B(8): GOTO 1900
1870 CN = B(8):DC = B(9)
1880  REM
1890  REM
1900  REM     METHOD 4 (AND SAMPLE VOLUME @ STD CONDITIONS)
1905  HOME : VTAB 10: HTAB 10: PRINT "CALCULATING"
1910  REM
1920  REM
1930 SV = 17.647 * (MV * GG) * (PB + (DH / 13.6)) / (460 + TM)
1940  IF WC$ = "E" GOTO 2000
1950 V1 = .04707 * CN
1960 V2 = .04715 * DC
1970 BW = (V1 + V2) * 100 / (V1 + V2 + SV)
1980  REM
1990  REM
2000  REM       STACK GAS PROPERTIES
2010  REM
2020  REM
2025  REM       DRY MOLECULAR WEIGHT
2026  REM
2030 MD = (.44 * CD) + (.32 * 02) + (.28 * (100 - CD - 02))
2034  REM
2035  REM       WET MOLECULAR WEIGHT
2036  REM
2040 MW = (MD * (1 - (BW / 100))) + (18 * BW / 100)
2044  REM
2045  REM       ABSOLUTE STACK PRESSURE
2046  REM
```

```
2050 PS = PB + (DS / 13.6)
2054  REM
2055  REM       STACK GAS VISCOSITY
2056  REM
2060 VS = 85.48 * CP * ((PP * (TS + 460) / (PS * MW)) ^ 0.5)
2070  REM
2080  REM
2090  REM      SAMPLE FLOWRATE (@ STACK CONDITIONS)
2100  REM
2110  REM
2120 QS = .0567 * (SV / RT) * (TS + 460) / (PS * (1 - (BW / 100)
))
2130  REM
2140  REM
2150  REM      RECYCLE FLOWRATE (@ STACK CONDITIONS)
2160  REM
2170  REM
2175  REM       RECYCLE GAS VISCOSITY
2176  REM
2180 UL = 51.05 + (.207 * (460 + TL)) + (.0000324 * ((460 + TL) ^
2)) + (53.145 * (O2 / 100))
2184  REM
2185  REM       RECYCLE FLOWRATE
2186  REM
2190 QR = ((180.10 * MR * PR / UL) + BR) * (PB + ((PI - PL) / 13
.6)) / PS * (460 + TS) / (460 + TL)
2200  REM
2210  REM
2220  REM      WATER CONTENT AND VISCOSITY OF MIXED GAS
2230  REM
2240  REM
2250 FW = BW * (QS / (QS + QR))
2260 UM = 51.05 + (.207 * (460 + TS)) + (.0000324 * ((460 + TS) ^
2)) - (74.143 * FW / 100) + (53.145 * (O2 / 100))
2270  REM
2280  REM
2290  REM      TOTAL FLOWRATE (@ STACK CONDITIONS)
2300  REM
2310  REM
2320 QT = ((180.10 * MT * PL / UL) + BT) * ((PB + (PI / 13.6)) /
PS) * (460 + TS) / (460 + TL) / (1 - (FW / 100))
2330  REM
2340  REM
2350  REM      PERCENT RECYCLE AND ISOKINETIC RATIO
2360  REM
2370  REM
2380 RP = ((QT - QS) / QT) * 100
2390 IS = (17.316 * SV * (460 + TS)) / (RT * (ND ^ 2) * PS * VS *
(1 - (BW / 100)))
2400  REM
2410  REM
2420  REM      CYCLONE CUT-POINTS
2430  REM
2440  REM
2450 MM = (MD * (1 - (FW / 100))) + (18 * FW / 100)
2460 D(1) = 0.15625 * ((MM * PS / (460 + TS)) ^ ( - .2091)) * (Q
T ^ ( - .7091)) * (UM ^ .7091)
2510  REM
2520  REM
2530  REM      CORRECTED RAW MASSES
```

```
2540  REM
2550  REM
2560 K = 1
2570 CM(K) = M(K) - CR
2590 CF = MF - FR - FB
2600 CI = MI - IR
2610 PT = CM(1) + CM(2) + CM(3) + CM(4) + . (5) + CF
2620 OT = PT + CI
2630  REM
2640  REM
2650  REM        PERCENT LESS THAN CALCULATIONS
2660  REM
2670  REM
2680 L(1) = CF * 100 / PT
2730  REM
2740  REM
2750  REM         CONCENTRATION CALCULATIONS
2760  REM
2770  REM
2780 K = 1
2790 W(K) = 35.315 * (CM(K) / SV)
2800 X(K) = .0154 * (CM(K) / (QS * RT))
2810 Y(K) = .0154 * (CM(K) / SV)
2820 Z(K) = 2.205 * (CM(K) / SV)
2840 WF = 35.315 * CF / SV
2850 XF = .0154 * (CF / (QS * RT))
2860 YF = .0154 * (CF / SV)
2870 ZF = 2.205 * (CF / SV)
2880 WP = 35.315 * (PT / SV)
2890 XP = .0154 * (PT / (QS * RT))
2900 YP = .0154 * (PT / SV)
2910 ZP = 2.205 * (PT / SV)
2920 WI = 35.315 * (CI / SV)
2930 XI = .0154 * (CI / (QS * RT))
2940 YI = .0154 * (CI / SV)
2950 ZI = 2.205 * (CI / SV)
2960 WO = 35.315 * (OT / SV)
2970 XO = .0154 * (OT / (QS * RT))
2980 YO = .0154 * (OT / SV)
2990 ZO = 2.205 * (OT / SV)
3000  REM
3010  REM
3020  REM        OUTPUT FORMAT
3030  REM
3040  REM
3050 A1$ = "      T(STK): ##<0#.# F     ;     DH(ORI): #<0#.## INWG
    ;    P(BAR) :  #<0#.## INHG"
3060 B1$ = "      T(RCL): ##<0#.# F     ;     DP(TOT): #<0#.## INWG
    ;    DP(STK):  #<0#.## INWG"
3070 C1$ = "      T(LFE): ##<0#.# F     ;     P(INL) : #<0#.## INWG
    ;    V(DGM) : ##<0#.### FT3"
3080 D1$ = "      T(DGM): ##<0#.# F     ;     DP(RCL): #<0#.## INWG
    ;    TIME   : ##<0#.## MIN"
3090 E1$ = "DP(PTO): #<0#.## INWG     ;     % CO2  :  #<0#.##"
3100 F1$ = "% O2    :  #<0#.##"
3110 G1$ = "NOZ (IN):  <0#.####"
3120 H1$ = "      ESTIMATE : ##<0#.# %    ;  CYCLONE 1: ###<0#.# M
G    ;   CYC RINSE    : ##<0#.# MG"
3130 I1$ = "         OR                    FILTER   : ###<0#.# MG
     FILTER HOLDER"
```

```
3140 J1$ = "      CONDENSER: ##<0#.# ML
    ;  RINSE        : ##<0#.# MG"
3150 K1$ = "      COLUMN    : ##<0#.# GM     IMPINGER           ;
      FILTER BLANK : ##<0#.# MG"
3160 L1$ = "RESIDUE : ###<0#.# MG        IMPINGER"
3170 M1$ = "    CALIBRATION VALUES
    RINSE        : ##<0#.# MG"
3180 N1$ = "      CP(PITOT) : <0#.###"
3190 O1$ = "      DH@(ORI)  : #<0#.###"
3200 P1$ = "      M(TOT LFE): <0#.####"
3210 Q1$ = "      B(TOT LFE): <0#.####"
3220 R1$ = "      M(RCL LFE): <0#.####"
3230 S1$ = "      B(RCL LFE): <0#.####"
3240 S2$ = "      DGM GAMMA : <0#.####"
3250 T1$ = "STACK VELOCITY (FT/SEC)       #<0#.##"
3260 U1$ = "STACK GAS MOISTURE (%)        #<0#.#"
3270 V1$ = "SAMPLE FLOWRATE (ACFM)         <0#.####"
3280 W1$ = "TOTAL FLOWRATE (ACFM)          <0#.####"
3290 X1$ = "RECYCLE FLOWRATE (ACFM)        <0#.####"
3300 Y1$ = "PERCENT RECYCLE               #<0#.#"
3310 Z1$ = "ISOKINETIC RATIO (%)         ##<0#.#"
3320 A2$ = "    CYCLONE #       ;      #<0#.## ; #<0#.#   ;   ###<0#.
#    ;  <0#.#####   ; <0#.#####   ;   <0#.#####"
3330 B2$ = "    BACKUP FILTER          ?-?-?-     ?-?-?-     ###<0#.#
    ;  <0#.#####   ; <0#.#####   ;  #<0#.###"
3340 C2$ = "    PARTICULATE TOTAL      ?-?-?-     ?-?-?-     ###<0#.#
    ;  <0#.#####   ; <0#.#####   ;  #<0#.###"
3350 D2$ = "    CONDENSABLES           ?-?-?-     ?-?-?-     ###<0#.#
    ;  <0#.#####   ; <0#.#####   ;  #<0#.###"
3360 E2$ = "    OVERALL CATCH          ?-?-?-     ?-?-?-     ###<0#.#
    ;  <0#.#####   ; <0#.#####   ;  #<0#.###"
3370  IF HC$ = "N" GOTO 3390
3380  PRINT D$;"PR#1"
3390  HOME : PRINT  TAB( 27);"EXHAUST GAS RECIRCULATION"
3400  PRINT  TAB( 33);"DATA REDUCTION"
3405  PRINT  TAB( 27);"VERSION 3.4   MAY 1986      "
3410  PRINT : PRINT "   TEST ID. CODE: ";ID$
3420  PRINT "    TEST LOCATION: ";LO$
3430  PRINT "    TEST SITE:     ";TS$
3440  PRINT "    TEST DATE:     ";TD$
3450  PRINT "    OPERATOR(S):   ";OP$
3460  PRINT : PRINT  TAB( 26);"***** ENTERED RUN DATA *****": PRINT

3470  PRINT "    TEMPERATURES           SYSTEM PRESSURES
  MISCELLANEA"
3480  CALL BU,R$,A1$,TS,DH,PB: PRINT R$
3490  CALL BU,R$,B1$,TR,PL,DS: PRINT R$
3500  CALL BU,R$,C1$,TL,PI,MV: PRINT R$
3510  CALL BU,R$,D1$,TM,PR,RT: PRINT R$
3520  CALL BU,R$,E1$,PP,CD: PRINT  TAB( 29);R$
3530  CALL BU,R$,F1$,02: PRINT  TAB( 56);R$
3540  CALL BU,R$,G1$,ND: PRINT  TAB( 56);R$
3550  PRINT : PRINT "   WATER CONTENT          RAW MASSES
        BLANK VALUES"
3560  IF WC$ = "C" GOTO 3580
3570 CN = 0:DC = 0:EW = BW: GOTO 3590
3580 EW = 0
3590  CALL BU,R$,H1$,EW,M(1),CR: PRINT R$
3600  CALL BU,R$,I1$,MF: PRINT R$
3610  CALL BU,R$,J1$,CN,FR: PRINT R$
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```
3620  CALL BU,R$,K1$,DC,FB: PRINT R$
3630  CALL BU,R$,L1$,MI: PRINT  TAB( 30);R$
3640  CALL BU,R$,M1$,IR: PRINT R$
3650  CALL BU,R$,N1$,CP: PRINT R$
3660  CALL BU,R$,O1$,HA: PRINT R$
3670  CALL BU,R$,P1$,MT: PRINT R$
3680  CALL BU,R$,Q1$,BT: PRINT R$
3690  CALL BU,R$,R1$,MR: PRINT R$
3700  CALL BU,R$,S1$,BR: PRINT R$
3710  CALL BU,R$,S2$,GG: PRINT R$
3720  PRINT : PRINT  TAB( 26);"****** REDUCED DATA ******": PRINT

3730  CALL BU,R$,T1$,VS: PRINT  TAB( 23);R$
3740  CALL BU,R$,U1$,BW: PRINT  TAB( 23);R$
3750  CALL BU,R$,V1$,QS: PRINT  TAB( 23);R$
3760  CALL BU,R$,W1$,QT: PRINT  TAB( 23);R$
3770  CALL BU,R$,X1$,QR: PRINT  TAB( 23);R$
3780  CALL BU,R$,Y1$,RP: PRINT  TAB( 23);R$
3790  CALL BU,R$,Z1$,IS: PRINT  TAB( 23);R$
3800  PRINT : PRINT "                              (UM)    (% C)   (MG/DN
CM)  (GR/ACF)  (GR/DCF)  (LB/DSCF)"
3810  PRINT "                                 (PARTICULATE)
                  (X 1E6)"
3815  PRINT
3820 K = 1
3830  CALL BU,R$,A2$,K,D(K),L(K),W(K),X(K),Y(K),Z(K): PRINT R$
3850  CALL BU,R$,B2$,WF,XF,YF,ZF: PRINT R$: PRINT
3860  CALL BU,R$,C2$,WP,XP,YP,ZP: PRINT R$: PRINT
3865  IF IR$ = "N" GOTO 3890
3870  CALL BU,R$,D2$,WI,XI,YI,ZI: PRINT R$: PRINT
3880  CALL BU,R$,E2$,WO,XO,YO,ZO: PRINT R$
3890  PRINT D$;"PR#0"
3900  REM
3910  REM
3920  REM       SAVING INPUT FILE TO DISK
3930  REM
3940  REM
3950  HOME
3960  VTAB (10): PRINT "DO YOU WISH TO SAVE THE INPUT FILE? ";: GET
FS$: PRINT FS$
3970  IF FS$ = "Y" GOTO 4000
3980  IF FS$ = "N" GOTO 4100
3990  PRINT "        Y OR N": GOTO 3960
4000  IF FS$ = "Y" THEN  PRINT "DO YOU WANT TO R)EPLACE OLD FILE
 OR MAKE A N)EW ONE? ";: GET NN$: PRINT NN$: IF NN$ = "N" THEN  INPUT
"ENTER NEW FILE NAME: ";ID$
4002  IF NN$ <  > "R" AND NN$ <  > "N" THEN  GOTO 4000
4005  IF WC$ = "C" GOTO 4020
4010 B(13) = 0
4020  PRINT D$;"OPEN" + ID$
4030  PRINT D$;"WRITE" + ID$
4040  PRINT ID$: PRINT LO$: PRINT TS$: PRINT TD$: PRINT OP$: PRINT
WC$
4050  FOR K = 1 TO 16: PRINT A(K): NEXT K
4060  FOR K = 1 TO 9: PRINT B(K): NEXT K
4070  FOR K = 1 TO 7: PRINT C(K): NEXT K
4075  PRINT IR$
4080  PRINT D$;"CLOSE" + ID$
4090  PRINT : PRINT "FILE SAVED AS:  ";ID$
4100  VTAB (18)
```

```
4110  END
63999 BU =  PEEK (121) + 256 *  PEEK (122) + 286: CALL BU:BU =  PEEK
(6) + 256 *  PEEK (7): CALL BU + 3: RETURN : REM

==> DO NOT EDIT 63999.

65535  REM
  BUILDUSING (2.0)   APPENDED.

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 SENSIBLE SOFTWARE


==> TO REMOVE 'APPENDAGE', ENTER:
]EXEC BU.STRIP

                    ]
```
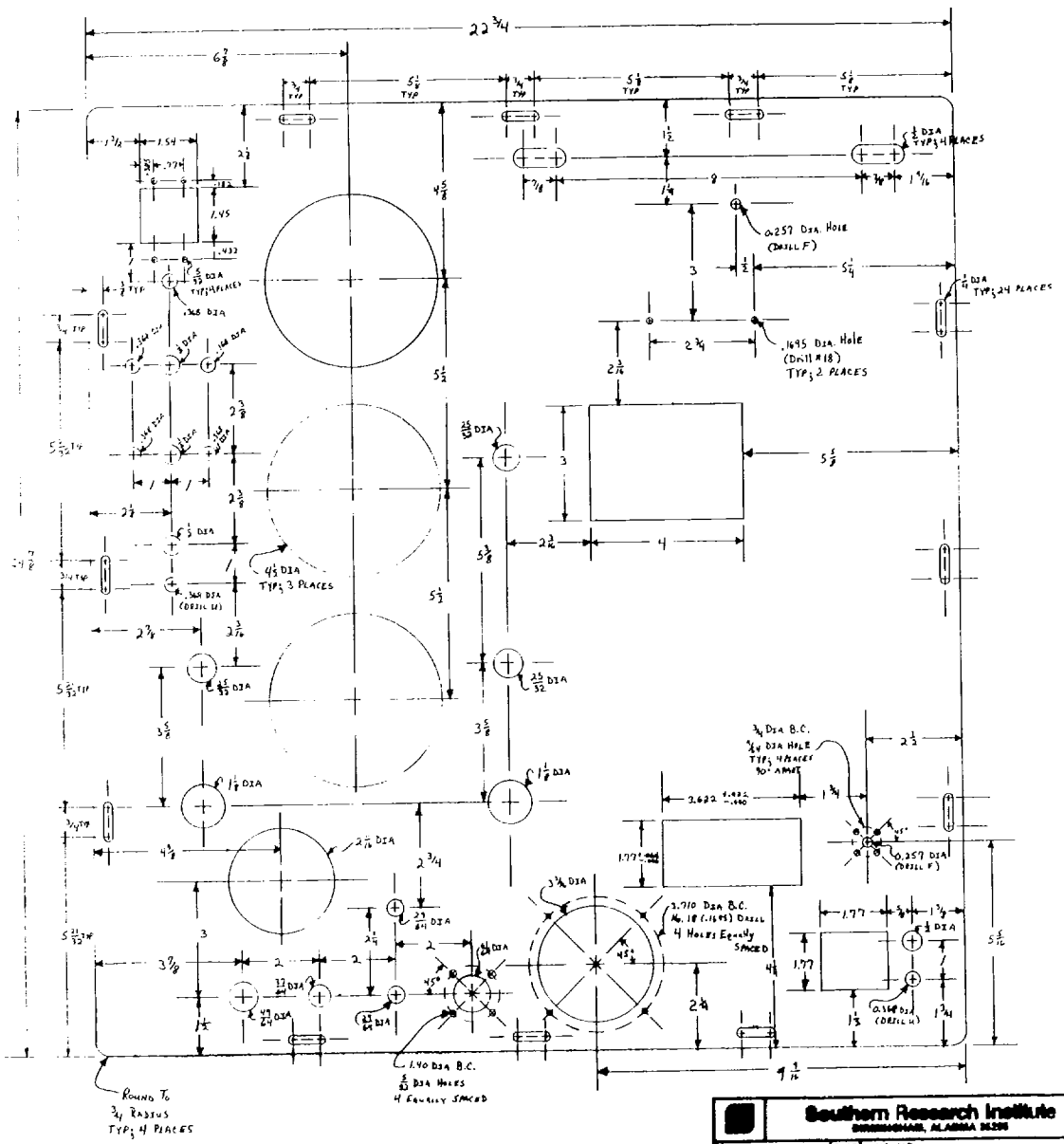

Appendix C

EGR SYSTEM DRAWINGS



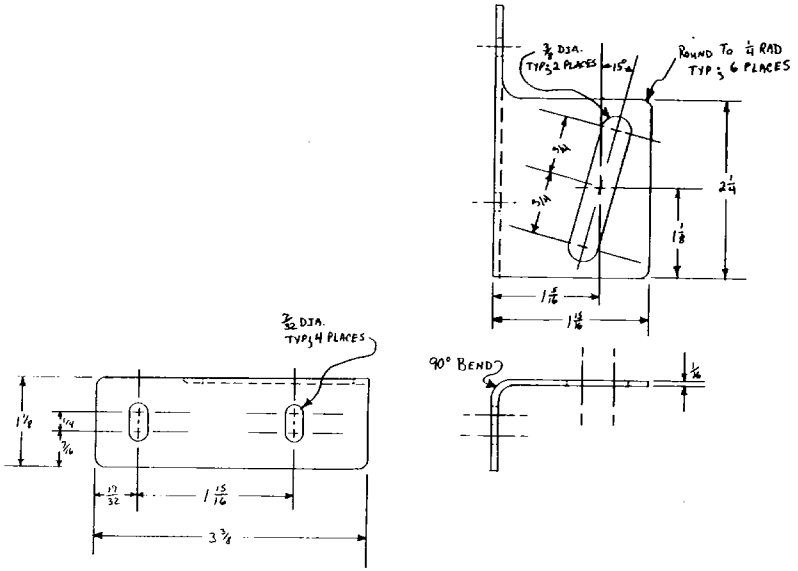
* Fabricate From 1/8" AL Plate

Southern Research Institute, Birmingham, Alabama 35205			TITLE: EGR PANEL (Control Box)
DRAWN: R.S. Martin	SIZE: C	DWG. NO.: 5785-1-C-01	REV:
DATE: 7-24-85			(1/2 SCALE) EGR SAMPLING SYSTEM

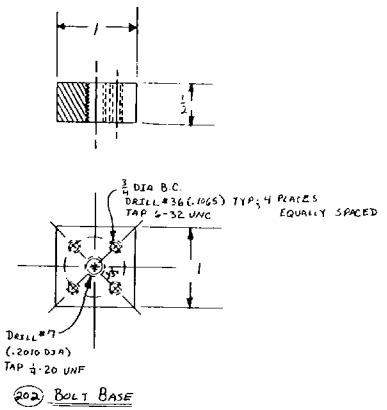
C-2

5598-54

	201	1 per set	Manometer Leveling Guide	3 3/8 x 1 5/16 x 1/16 AL PLATE
	202	1 per set	Bolt Base	1 x 1 x 1/2 AL



(201) MANOMETER LEVELING GUIDE



(202) BOLT BASE

TOLERANCES UNLESS OTHERWISE NOTED	
FRACTIONS	± 1/32
DECIMALS	± .010
ANGLES	± 1°
FINISH	
APPROVED	
CHECKED	
DRAWN R. Martin	

DATE	REVISIONS	ZONE	NO.
			A

SOUTHERN RESEARCH INSTITUTE
BIRMINGHAM, ALABAMA 35205

TITLE EGR SAMPLING SYSTEM

Manometer Leveling Accessories

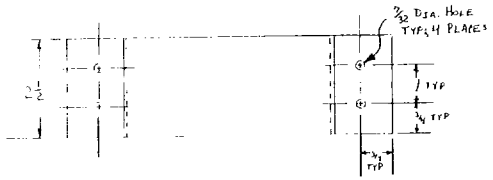
SCALE Full
DATE 7-25-85
DWG. NO. 5785-1-C-02

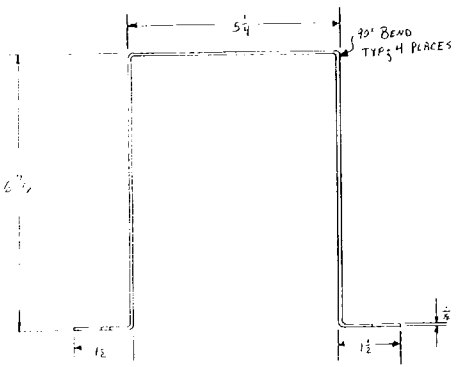
REPRINT CORP. 174

C-3

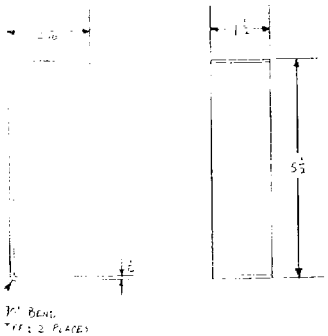
5598-55

FIND NO.	PART NO.	REQD	DESCRIPTION	MATERIAL
ASSY 3A	301	1 PER	FRAME BRACE $5\frac{1}{2} \times 2\frac{1}{16} \times 1\frac{1}{2}$	$\frac{1}{16}$ AL PLATE
ASSY 3A	302	1 PER	BOTTOM SUPPORT FRAME $5\frac{1}{4} \times 6\frac{3}{4} \times 2\frac{1}{2}$	$\frac{1}{16}$ AL PLATE
—	303	1 PER	TOP D&M SUPPORT $1 \times 3\frac{1}{2} \times 2\frac{1}{8}$	$\frac{1}{16}$ AL PLATE

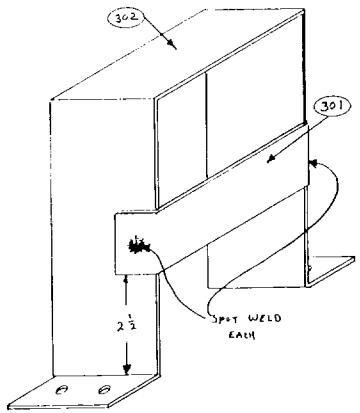




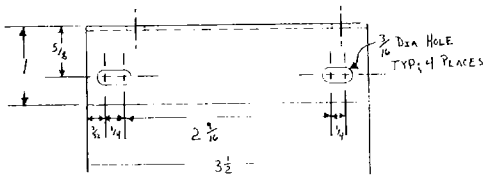
302 BOTTOM SUPPORT FRAME

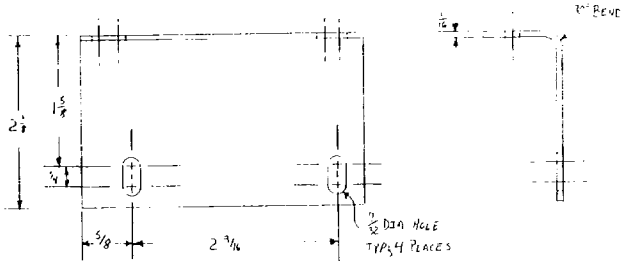


301 FRAME BRACE



ASS'Y 3A BOTTOM D&M SUPPORT ASSEMBLY





303 TOP (CO. PANEL) D&M SUPPORT

REV	DESCRIPTION	DATE	BY

REVISIONS

NEXT ASSY.	QTY.

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES ON FRACTIONS ANGLES DECIMALS .X ± .05 .XX ± .010 .XXX ± .010

REQ. BY	R Mailen
ENGR	R Mailen
DFTMN	R Mailen
CHK	
PROJ	5755-1
APPD.	
DATE	7-25-85

Southern Research Institute
BIRMINGHAM, ALABAMA 35255

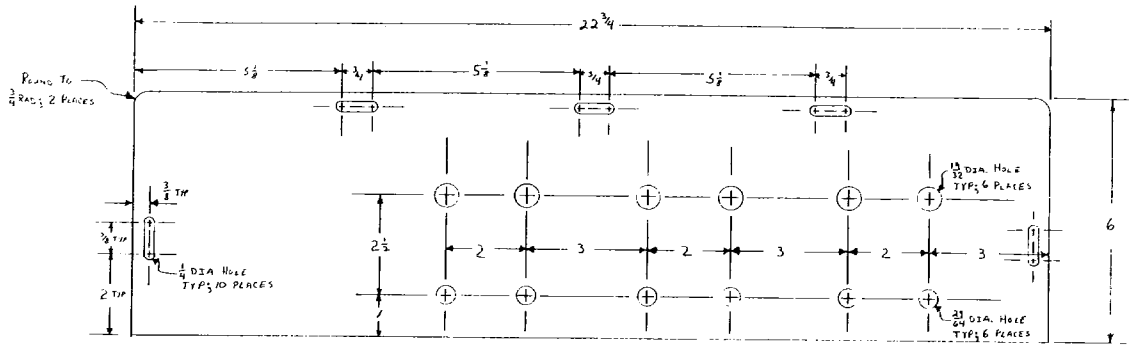
EGR SAMPLING SYSTEM
D&M SUPPORTS

SIZE C | DWG NO. 5755-1-C-03 | REV

SCALE FULL EXCEPT AS NOTED | SHEET

5598-56

FIND NO.	PART NO.	REQ'D	DESCRIPTION	MATERIAL
			$22\frac{3}{4} \times 6$	$\frac{1}{8}$ AL Plate



REV.	DESCRIPTION	DATE	BY
	REVISIONS		

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES ON:
FRACTIONS: ANGLES:
DECIMALS: .X ± .05 | .XX ± .05 | .XXX ± .010

REQ. BY	R.S. Martin
ENGR.	R.S. Martin
DFTMN.	R.S. Martin
CHK.	
PROJ.	5785-1
APPD.	
DATE	7-31-85

Southern Research Institute
BIRMINGHAM, ALABAMA 35255

EGR SAMPLING SYSTEM
Back Panel (Magnehelic Face Plate)

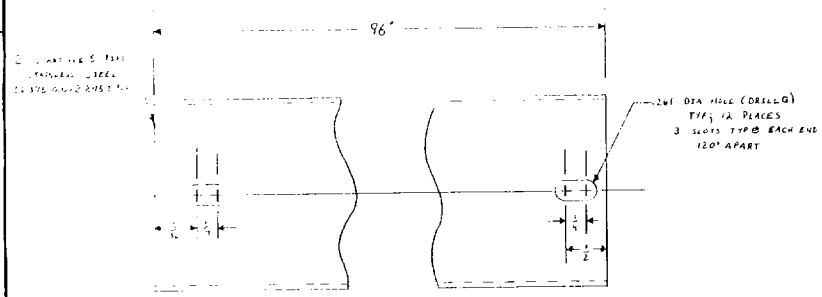
SIZE C | DWG NO. 5785-1-C-24 | REV
SCALE HALF | SHEET

NEXT ASSY.	QTY.

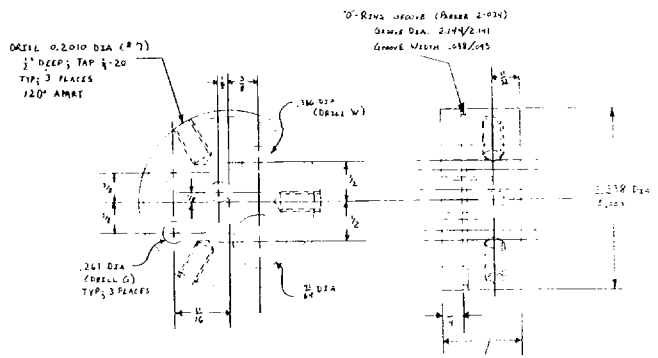
C-5

5598-57

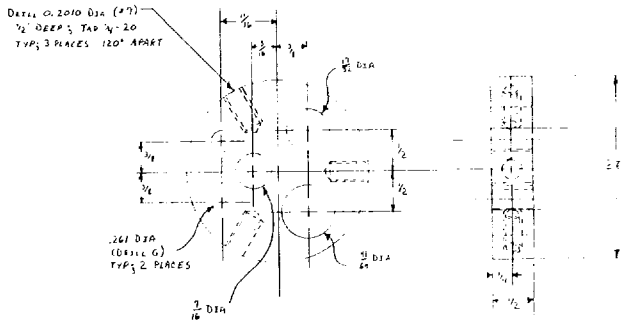
FIND NO.	PART NO.	REQ'D	DESCRIPTION	MATERIAL
501		1 ea.	EGR PROBE SHEATH 2 SCH 5 S.S. PIPE	
502		1 ea.	PROBE CAP (FRONT)	
503		1 ea.	PROBE CAP (EXIT)	



501 EGR PROBE SHEATH



502 PROBE CAP (FRONT)



503 PROBE CAP (EXIT)

REV	DESCRIPTION	DATE	BY
	REVISIONS		

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES. TOLERANCES ON. FRACTIONS: ANGLES: DECIMALS .X ± .05 .XXX ± .010

REQ BY RSMARTIN
ENGR
DFTMN
CHK
PROJ 5785-1
APPD
DATE 8-7-85

NEXT ASSY. | QTY.

Southern Research Institute
BIRMINGHAM, ALABAMA 35255

EGR SAMPLING SYSTEM
PROBE COMPONENTS

SIZE C | DWG NO 5785-1-C-5 | REV

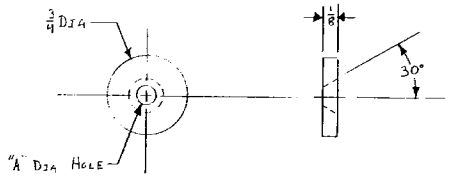
SCALE — | SHEET

C-6

5598-68

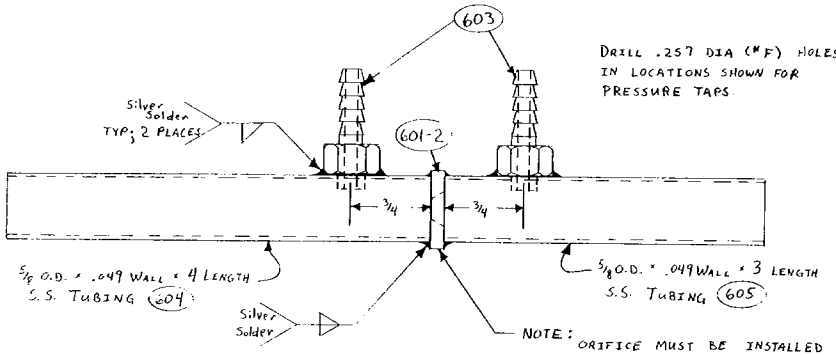
AF 25122A

Item	"A" ; INCHES
601	0.1800 (DRILL 15)
601.5	0.1285 (DRILL 30)
602	0.0935 (DRILL 42)

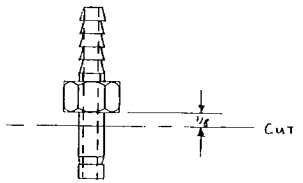


(601) - (602) ORIFICE PLATE

FIND NO.	PART NO.	REQ'D	DESCRIPTION	MATERIAL
601 / 601.5		1 / 1	ORIFICE PLATE 3/4 O.D. x (.1800) I.D. x 1/8 / ORIFICE PLATE 3/4 O.D. x .1285 I.D. x 1/8	S.S. / S.S.
602		1	ORIFICE PLATE 3/4 O.D. x .0935 I.D. x 1/8	S.S.
603		6	PRESSURE TAP (HC" TUBE ADAPTER; SWAGELOK "B-4-HC-A-401)	BRASS
604		3	TUBING 5/8 O.D. x .049 WALL x 4 Length	S.S.
605		3	TUBING 5/8 O.D. x .049 WALL x 3 Length	S.S



DRILL .257 DIA ("F") HOLES IN LOCATIONS SHOWN FOR PRESSURE TAPS



(603) PRESSURE TAP

ASS'Y (6A) SAMPLE ORIFICE ASSEMBLY

REV.	DESCRIPTION	DATE	BY

REVISIONS

NEXT ASSY.	QTY.

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES. TOLERANCES ON:
FRACTIONS: ANGLES:
DECIMALS
.X ± .05 | .XX ± .05 | .XXX ± .010

REQ. BY	RSMartin
ENGR.	RSMartin
DFTMN.	RSMartin
CHK.	
PROJ.	5785-1
APPD.	
DATE	8-7-85

Southern Research Institute
BIRMINGHAM, ALABAMA 35255

EGR SAMPLING SYSTEM
SAMPLE ORIFICE ASSEMBLY

SIZE	DWG. NO.	REV.
B	5785-1-B-06	

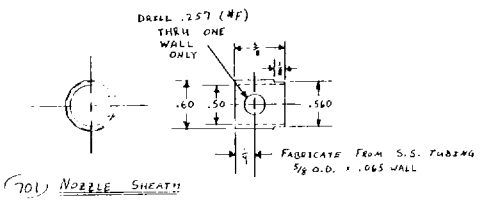
SCALE FULL SHEET

REPRINT CORP. 6-82

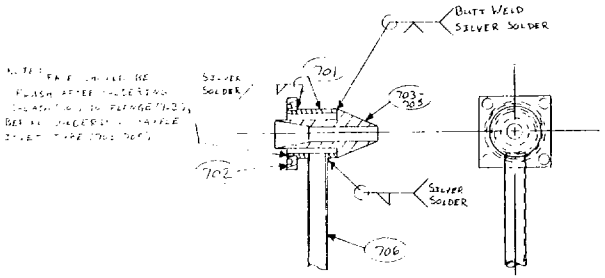
C-7

5598-59

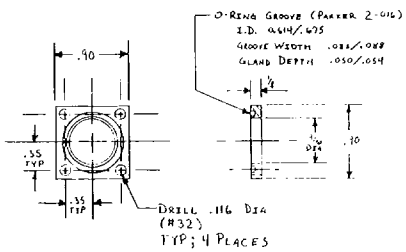
FIND NO	PART NO	REQ'D	DESCRIPTION	MATERIAL
701		3 PER SET	NOZZLE SHEATH .60 OD x .50 ID x 5/8 L	S.S. TUBE
702		3 PER SET	NOZZLE FLANGE .90 x .70 x 1/4	S.S. PLATE STOCK
703-705		1 EA	SAMPLE INLET TUBE .60 DIA x 1 3/4 L	S.S.
706		3 PER SET	RECYCLE TUBE 1/4 O.D. x .035 WALL x 5 LONG	S.S.



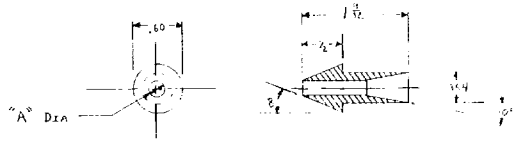
(701) NOZZLE SHEATH



ASSY (1A) EGR NOZZLE ASSEMBLY



(702) NOZZLE FLANGE



ITEM NO.	DIM. A"	DIM. B
703	1/8"	25° 25.5'
704	3/16"	22° 25'
705	1/4"	19° 24'

(703-705) SAMPLE INLET TUBE

REV	DESCRIPTION	DATE	BY

REVISIONS

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES ON FRACTIONS. ANGLES. DECIMALS .X ± .05 .XX ± .010 .XXX

REQ. BY	RS MARTIN
ENGR	RS MARTIN
DFTMN	RS MARTIN
CHK	
PROJ	5985-1
APPD	
DATE	8-26-85

NEXT ASSY. | QTY.

Southern Research Institute
BIRMINGHAM, ALABAMA 35255

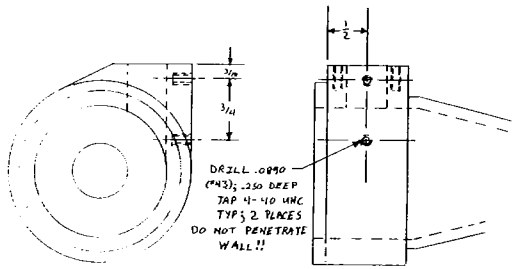
EMISSION GAS RECYCLE SAMPLING SYSTEM
EGR NOZZLE ASSEMBLY

SIZE C | DWG NO 5985-1-0-01 | REV

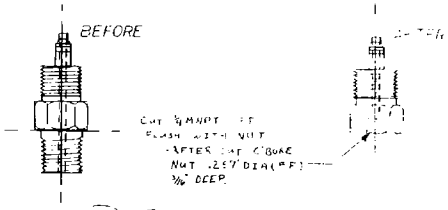
SCALE FULL | SHEET

5598-60

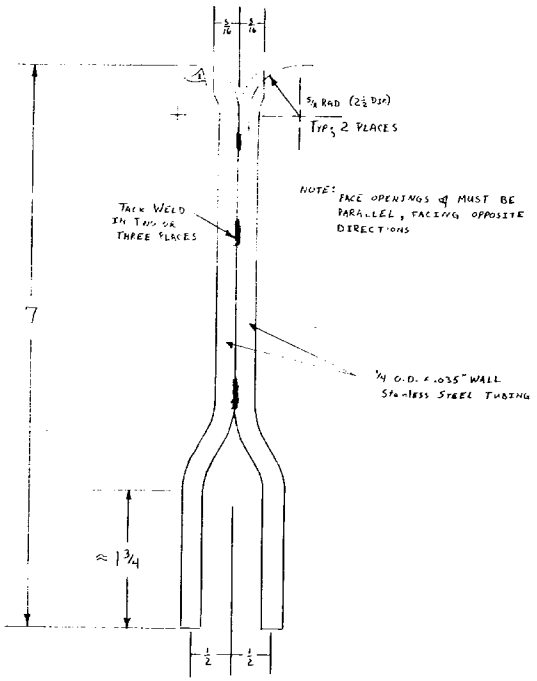
FIND NO.	PART NO.	REQ'D	DESCRIPTION	MATERIAL
801		4 PER SET	FLEX-LINE FITTING, 1/8 MALE NPT	S.S.
802		1 PER SET	PITOT CLAMP, 1 x 5/8 x 1/16	S.S.
803		1 PER SET	CYCLONE I MODIFICATION; ADDED 1/4 TAP TO P/N 5785-1	
804		1 PER SET	S-TYPE PITOT TUBE, 1/4 O.D. x .035 WALL	S.S.



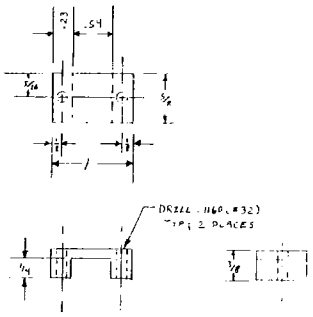
803 CYCLONE I MODIFICATION



801 FLEX-LINE FITTING



804 S-TYPE PITOT TYPE



802 PITOT CLAMP

REV	DESCRIPTION	DATE	BY

REVISIONS

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES
TOLERANCES ON:
FRACTIONS: ANGLES.
DECIMALS
.X ± .05 | .XX ± .010 | .XXX ± .010

REQ. BY	RSMartin
ENGR	RSMartin
DFTMN.	RSMartin
CHK.	
PROJ.	5785-1
APPD.	
DATE	8-30-85

NEXT ASSY. | QTY.

Southern Research Institute
BIRMINGHAM, ALABAMA 35255

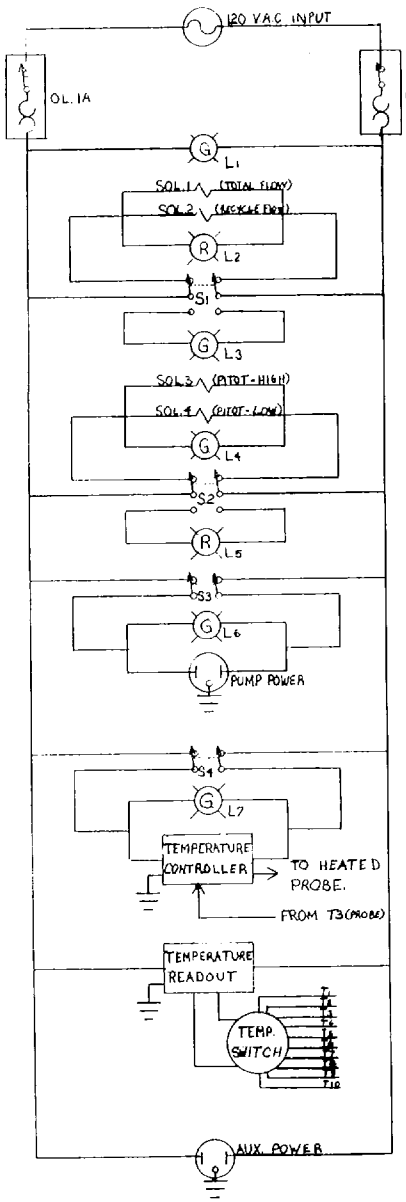
EMISSION GAS RECYCLE SAMPLING SYSTEM
PITOT ASSEMBLY

SIZE C | DWG NO 5785-1-C-08 | REV

SCALE FULL | SHEET

C-9

5598-61



SWITCHES

S1	DPDT (ON-ON) RATED 15 AMPS @ 120 V.A.C.
S2	DPDT (ON-ON) RATED 15 AMPS @ 120 V.A.C.
S3	DPDT (ON-OFF) RATED 15 AMPS @ 120 V.A.C.
S4	DPDT (ON-OFF) RATED 15 AMPS @ 120 V.A.C.

LAMPS

L1	POWER ON INDICATOR
L2	INDICATES SOL 1 AND 2 ARE ENERGIZED
L3	INDICATES SOL 1 AND 2 ARE DEENERGIZED
L4	INDICATES SOL 3 AND 4 ARE ENERGIZED
L5	INDICATES SOL 3 AND 4 ARE DEENERGIZED
L6	INDICATES PUMP POWER ON
L7	INDICATES TEMP. CONTROLLER POWER ON

NOTE: ALL LAMPS RATED AT 120 V.A.C.

TEMP. CONTROLLER

OMEGA MODEL 6103 CONTROLLER
T3 MONITORS TEMPERATURE AT PROBE
CONTROLLED AC OUTPUT TO HEATERS

TEMP. READOUT

RANGE -50°F to 1999°F
TOTAL READING ACCURACY ± 2.5°F
OPERATING VOLTAGE 120 V.A.C.
OPERATING TEMP. 14°F to 122°F

TEMP. SELECTOR SWITCH

T1	STACK TEMPERATURE
T2	RECYCLE TEMPERATURE
T3	PROBE TEMPERATURE
T4	TOTAL LFE TEMPERATURE
T5	SAMPLE DGM TEMPERATURE
T6	AMBIENT 1 TEMPERATURE
T7	AMBIENT 2 TEMPERATURE
T8	NOT CONNECTED
T9	NOT CONNECTED
T10	NOT CONNECTED

SOLENOIDS

SOL. 1	N.O. 2-WAY DIRECT ACTING
SOL 2	N.O. 2-WAY DIRECT ACTING
SOL. 3	N.C. 3-WAY VALVE
SOL. 4	N.C. 3-WAY VALVE

CIRCUIT BREAKER

OL 1 RATED 25 AMPS @ 250 VOLTS MAX
NOTE: CIRCUIT BREAKER USED AS OVERLOAD PROTECTION AND ON-OFF SWITCH.

PLUGS

PUMP POWER - STANDARD FEMALE [illegible]
AUX. POWER - STANDARD FEMALE [illegible]

NOTES:
1. FRONT PANEL GROUNDED

PART NO.	REQ'D	DESCRIPTION	MATERIAL

REV.	DESCRIPTION	DATE	BY
	REVISIONS		

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES. TOLERANCES ON: FRACTIONS: ANGLES: DECIMALS .X ± .05 .XX ± .010 .XXX ± .010

NEXT ASSY. | QTY.

REQ. BY R.S. MARTIN
ENGR. R.S. MARTIN
DFTMN. S.J. GALLAGHER
CHK.
PROJ. 5785-1
APPD.
DATE 9-6-85

Southern Research Institute
BIRMINGHAM, ALABAMA 35255

EMISSION GAS RECYCLE SAMPLING SYSTEM
EGR CIRCUIT DIAGRAM

SIZE C | DWG. NO. 5785-1-C-15 | REV
SCALE NA | SHEET

5598-62

C-10

UNIT CONVERSION TABLE

English to Metric

1 in	=	25.40 mm = 2.540 cm
1 ft	=	0.3048 m
1 ft^3	=	0.02832 m^3 = 28.32 liters
1 lb	=	453.6 gm
1 grain	=	0.06480 gm
1 lb/ft^3	=	1.602 x 10^4 gm/m^3
1 gr/ft^3	=	2.288 gm/m^3

Metric to English

1 cm	=	0.3937 in.
1 m	=	3.281 ft
1 m^3	=	35.31 ft^3
1 gm	=	0.002205 lb
1 gm	=	15.43 grains
1 gm/m^3	=	6.243 x 10^{-5} lb/ft^3
1 gm/m^3	=	0.4370 gr/ft^3

Others

1 m^3	=	10^3 liters = $10^6 cm^3$
1 cm^3	=	1 cc = 10^{-3} liters
1 µm	=	10^{-6} m = 10^4 Å
1 lb	=	7,000 grains
1 in. Hg	=	13.6 in. H_2O
R	=	0.08205 liter-atm/mole-K
1 gm/gm-mole	=	1 lb/lb-mole = 1 amu
°R	=	°F + 460
°K	=	°C + 273.2
°C	=	(5/9) (°F - 32)
°F	=	(9/5) °C + 32
1 ft/sec	=	0.6818 miles/hr

Nozzle Sizes

Fractional Inches		Decimal Inches		Decimal mm
1/8	=	.125	=	3.18
3/16	=	.1875	=	4.76
1/4	=	.250	=	6.35
5/16	=	.3125	=	7.94
3/8	=	.375	=	9.53
1/2	=	.500	=	12.70

Normal conditions are 20.0°C, 760 Torr, (68°F, 29.92 in. Hg) on a dry basis.
MMW of Standard Air, dry is 28.95 amu.
The Pitot/coefficient, C_p, for a isolated Type S Pitot Tube may be assigned a baseline value of 0.84 if the geometry of the Pitot meets the dimensional critera given in Method 2.
$\Delta H@$ is defined as the Method 5 orifice pressure differential (in. H_2O) that correlates to 0.75 cfm of dry air at 528°R and 29.92 in. Hg.
$V_A = (P_N/P_A)\ (T_A/T_N)\ V_N$, for absolute temperature.